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NASA Lewis Research Center Lean-, Rich-Burn Materials Test Burner Rig

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Brook Park, Ohio

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INTRODUCTION

The rich-burn quick-quench lean-burn (RQL or RBQQ) combustor is one potential concept being considered for the next generation high speed civil transport (HSCT) aircraft (ref.1). The rationale for developing this and other alternate combustor concepts derives primarily from NO_x emission considerations (ref.1-3). Ceramic matrix composites (CMC's) are being pursued as candidate construction materials for the RQL combustor. Based mainly on temperature capability, thermal conductivity and density considerations, silicon based CMC's (fiber reinforced SiC and Si_3N_4) are at this time prime candidates. How such silicon based materials will behave in the quasi reducing environment (ref.4) of the rich-burn section of the RQL is of fundamental importance to materials development. As part of NASA's Enabling Propulsion Materials (EPM) program, efforts are underway at Lewis Research Center (LeRC) to answer this question. In addition to theoretical chemical analyses and laboratory type studies (ref.4-5 and references cited therein), the EPM program mandated that a test rig be developed in which sample materials could be subjected to the rich-burn environment (equivalence ratio, temperatures and flow velocities) projected for the RQL burning jet fuel. The high pressure burner rig in existence at LeRC was proposed as a possible facility. If this rig could be adapted to the needs at hand, it would expedite the onset of materials testing and be more economical than development of a new rig.

Initial experiments demonstrated the feasibility of rich-burn operation. However, subsequent studies concluded that (1) the fuel-air mixing was not satisfactory, (2) sufficiently low flow velocities could not be achieved, (3) combustor durability was not satisfactory, (4) a water cooled sample holder would be necessary and (5) the by-products of rich-burn operation must be environmentally safe. At this point it was presumed that the rig could be relatively easily modified to meet the program required test conditions. This report is intended mainly for the EPM community and its purpose is to describe and document the modified rig and present the range of operational parameters available.

Modifying the existing facility to meet EPM test requirements was a more formidable task than originally anticipated. Key efforts included the implementation of a state-of-the-art air blast fuel nozzle, the installation of a stack burner for the removal of environmentally hazardous emissions, and the use of an inert gas to cool observation windows. Materials durability was another major hurdle in that rig components were required to have the same durability that forms the basis for developing new combustor materials. Fortunately, weight constraints (which are a major driver in the HSCT program) do not apply to rig testing. In addition, the rig could use cooling approaches unavailable in flight hardware. Lastly, computer control was added to ensure quality and repeatability of test conditions. After nearly a two year intensive effort, the rig has been brought to the point where it satisfactorily meets EPM testing requirements and the materials test program has been initiated.

RIG HARDWARE & TEST FACILITY SYSTEMS

A schematic representation of the burner rig configuration is shown in Figure 1. The combustor burns jet fuel and air in controlled ratios, the combustion products flow downstream and impinge on samples supported in a water cooled holder in the test section. After passage through the test section the combustion gases pass through a water cooled orifice plate and into a quench section where they are cooled by a water spray before being vented to the atmosphere. The rig is constructed such that it can be operated to pressures above 5 MPa (800 psig). In addition to the combustor rig the test cell houses an associated 400 hp compressor which delivers combustion air to the rig. The test cell layout is shown in Figure 2, and a photograph of the rig is shown in Figure 3. Description of the rig's various components and systems is best accomplished by considering them individually.

<u>COMBUSTOR SECTION</u> The combustor section consists of a housing, combustion liner, fuel injection nozzle, air swirl plate, turbulator and instrument ring. The combustor section (less the turbulator) is shown in cross-section in Figure 4. Air enters the housing through a 5 cm (2 in) diameter pipe, passes through the annulus between the housing and the outside diameter of the combustion liner. A distribution system assures uniform air flow over the outside diameter of the liner. The combustion liner is thus cooled by the inlet air which typically enters the housing at 100°C (200°F). After passing over the liner, the air enters the interior of the combustion liner through the swirl plate and swirl section of the fuel nozzle. The air temperature is increased by heat picked up as the air flows over the liner. The temperature rise depends on the combustor temperature (fuel-to-air ratio) and air mass flow rate. With a mass flow rate of 0.45 kg/sec (1 lbm/sec) and the range of temperatures produced by combustion, the air actually enters the combustion liner between 150 and 200°C (300-400°F). The combustor housing is constructed of stainless steel while the liner and swirl plate are fabricated from Inconel 601 and 600, respectively. A photograph of the liner, swirl plate, and fuel nozzle assembly is shown in Figure 5. The liner has an inside diameter of 10 cm (4 in) and is 43 cm (17 in) overall in length. The liner has a wall thickness of 0.02 cm (0.08 in) and ribs (cooling fins) which are 0.28 cm (0.11 in) high by 0.25 cm (0.10 in) wide. There are forty ribs on the liner. A Y_2O_3-ZrO_2 (yttria-stabilized zirconia) thermal barrier coating, 0.038 cm (0.015 in) thick, is plasma sprayed over a 0.013 cm (0.005 in) NiCrAlY bond coat on the

interior of the liner.

The swirl plate is fixed in position and supported in the housing at three points by pins. The liner is fixed in position and supported at the downstream flanges of the housing. The inside diameter of the liner fits around the swirl plate and has three slots which allow it to grow in length (over the swirl plate and beyond the pins) as it is heated. As shown in Figure 6, the swirl plate has a single row of radial holes to produce air swirl (approx. 60°) with the same rotation as that produced by the air-blast fuel nozzle. In addition to the swirl angle, the geometry of the dome (conical expansion configuration) is critical in achieving the proper fuel-air mixing (ref. 6). The structure appended to the swirl plate accommodates the spark plug and hydrogen pilot inlet used for ignition.

The air-blast fuel nozzle is supported in a port on the housing and seats in the center of the swirl plate. This nozzle, graciously supplied by Textron Fuel Systems Inc., is the type used in Pratt and Whitney's 2037 turbine engine and it is considered to be a state-of-the-art nozzle with respect to fuel atomization. Injected fuel is mixed with air in the nozzle and sheared through a nozzle passage before mixing with additional air through swirl vanes in the nozzle. Additional combustion air is added to the combustor through the swirl plate and via the small clearance between the swirl plate outside diameter and liner inner diameter. Under cold flow conditions with 0.45 kg/sec (1 lbm/sec) air flow, the pressure drop across the combustor liner inlet is about 40 kPa (6 psi).

The turbulator, a pressure constrictor with an orifice diameter of 6.35 cm (2.5 in), is located at the exit end of the combustor liner. This orifice is water cooled and also protected with a thermal barrier coating, and its function is to provide more uniform burning. Immediately downstream of the turbulator is a 10.2 cm (4 in) long by 15.2 cm (6 in) inside diameter water-cooled instrument ring which is also protected with a thermal barrier coating. This ring has four 1.27 cm (0.5 in) diameter ports equally spaced circumferentially and radially directed. These ports provide access for thermocouples and pressure taps. Three Pt-Pt13Rh thermocouples in closed end Pt10Rh tubes located in this instrument ring are used for rig monitoring purposes. These couples do not penetrate to the center of the gas path; rather they protrude only slightly beyond the interior wall and thus they only provide relative temperatures. This arrangement was found to be necessary to provide reasonable thermocouple life.

TEST SECTION The test section consists of a stainless steel water cooled tee with an inside diameter of 15.2 cm (6 in). The straight through ends of the tee are flanged (6 in, 800 pound ASA flanges) to mate with the combustor housing (with the turbulator and instrument ring contained between) and quench section respectively. The side arm of the tee is a 15.2 cm (6 in) inside diameter port that mates with the sample holder housing section through a Grayloc hub flange. The wall of the tee opposite the side arm has a 0.159 cm (0.625 in) inside diameter port to accept a water cooled thermocouple probe. The water cooled section of this probe is 0.127 cm (0.5 in) in diameter and extending beyond this is a 7.62 cm (3 in) length of Pt10Rh tube.

Inside this tube is a double bore alumina tube which carries a Pt-Pt13Rh thermocouple. The alumina tube extends 0.64 cm (0.25 in) beyond the Pt10Rh tube and the thermocouple bead is exposed at the end of the alumina tube. This thermocouple is positioned such that the junction is located on the centerline of the test section, thus in the center of the combustion product flow path and directly behind the samples when the sample holder is inserted.

On the top centerline of the tee straight section (90 degrees circumferentially from the side arm) is a nominal 3.8 cm (1.5 in) diameter by 7.6 cm (3 in) long tube attached to a viewport assembly. This tube is 3.8 cm (1.5 in) forward of the tee side arm centerline and centered with respect to the gas flow path. The viewport assembly consists of a housing containing a 5.08 cm (2 in) diameter by 5.08 cm (2 in) thick quartz window with appropriate pressure seals. There is a 1.27 cm (0.5 in) diameter side port in the tube below the window. A plate with a 1.27 cm (0.5 in) diameter hole is located in the tube a short distance below the side port. The section between the window and plate is pressurized by flowing nitrogen (1.5 ACFM @ 4MPa (550 psig)) through the side port. The nitrogen flow maintains a positive pressure in the enclosure which in turn keeps the window cool and clean. The viewport is used for observing a sample under test with a two-color optical pyrometer and video camera.

QUENCH AND EXHAUST SYSTEM The quench section attached to the downstream end of the test section consists of an exhaust orifice, a quench ring, a quench pipe and transition piping to the back pressure exhaust valve. The exhaust orifice is a water cooled plate with a 5 cm (2 in) diameter orifice in its center. The purpose of this orifice is maintain a higher pressure in the test section than in the quench section and thereby prevent water vapor from entering the test section. The quench ring is a 10.1 cm (4 in) long water cooled cylinder with holes in its interior periphery and a spray nozzle in the center on its inside diameter. Cooling water sprays through the holes and nozzle to cool the combustion product gas flow. Typically a water flow rate of 38 l/min (10 gpm) is used to cool the gas to below 120°C (250°F) by the time it reaches the end of the 15.2 cm (6 in) diameter by 0.92 m (3 ft) long quench pipe.

Gas flow from the quench pipe is diverted from the horizontal to a vertical flow path by transition piping and carried to the exhaust valve. This air operated automatic valve is used to control the pressure in the test section, as measured by a pressure transducer connected to the test section.

Downstream of the exhaust valve the cooled combustion product gas flows through a water separator to remove the excess water not converted to steam. The water (and any soot contained within as a result of fuel-rich operation) is pumped into an appropriate sewer. The gases exiting the water separator pass through the cell ceiling and enter a natural gas fired stack burner rising 7.3 m (24 feet) above the roof. The rig combustion gases are diluted with air and the combustible components are ignited by the 788°C (1450°F) natural gas flame. Thus the CO and small quantities of H_2S found in the combustion products during fuel-rich operation are reduced to levels which meet or exceed environmental discharge standards.

SAMPLE HOLDER SECTION The sample holder section, shown schematically in Figure 7, consists of the sample holder, its support shaft, the translation mechanism, and the pressure containment vessel. Figure 8 is a photograph of the thermal barrier coated, water-cooled sample holder with two samples in place. The samples are held in the holder with lava or superalloy blocks which have slots appropriately sized to the sample width and thickness. The lava blocks are preferred, because they provide some thermal insulation of the sample from the water cooled holder, but in some instances are subject to cracking. In such circumstances we have used superalloy (Haynes 214) blocks and found the heat loss to be acceptable. The required sample length is 7.5 cm (3 in) and any combination of sample widths can be accommodated to a maximum width of about 3.0 cm (1.2 in). Sample thickness should be in the nominal range from 0.25 to 0.50 cm (0.1 to 0.2 in). The samples extend into the lava blocks approximately 0.64 cm (0.25 in) on each end.

The sample holder is welded to the end of a 2.5 cm (1.0 in) diameter shaft which carries the supply and return water for the holder. This shaft passes through two bearings and is attached to a pair of air-operated cylinders which allow translation (by remote control) of the holder to the center line of the test section flow path. Between the two bearings the shaft can be broken for ease of assembly and maintenance. The air cylinders and flexible water feed and return lines are contained in the pressure containment vessel.

This vessel is pressurized with nitrogen to assure that no combustion product gases enter the vessel through the slight leakage associated with clearances in the final bearing. The use of nitrogen is required because of the fuel-rich environment. A differential pressure transducer and automatic valve are used to maintain the pressure in the vessel 150 kPa (25 psi) greater than that in the test section.

The sample holder is thermal barrier coated (Y_2O_3-ZrO_2) everywhere except in the recesses for the lava blocks and in the area of the attachment screws. Room temperature, deionized water is supplied to the holder by a closed loop water system with high pressure pump. The return leg of the water system passes through a heat exchanger before being returned to the 380 liter (100 gallon) supply reservoir. The temperature of the return water is monitored immediately after it exits the pressure vessel to assure proper cooling of the sample holder. With a water flow rate of 9.5 l/min (2.5 gpm) through the sample holder and a gas temperature as high as 1550°C (2825°F), the temperature rise of the water after passing through the holder is only about 25°C (50°F).

It should be noted that when the sample holder is in the retracted position the samples are out of the flow path but still in a high temperature environment.

AIR AND FUEL SUPPLY SYSTEMS A compressor, capable of delivering 4.4 kg/sec (2 lbm/sec) of air at 7 MPa (1000 psig), delivers air to a large roof mounted ballast reservoir which automatically vents to atmosphere to maintain the pressure near 5 MPa (800 psig). Filtered laboratory service air at 850 kPa (125 psig) supplies the compressor. Air from the reservoir is piped to the rig inlet through a filter, flow measuring Venturi and automatic valve.

Fuel is supplied from a 6000 gallon underground tank. Low and high pressure fuel pumps in series deliver fuel to the rig through filters, an automatic valve and flow rate transducer. The fuel system is plumbed with return lines so excess fuel delivered by the pumps can be returned to the tank. The low pressure pump is located outside the building at the fuel tank and the high pressure pump, automatic valve and flow transducer are located in the test cell.

<u>IGNITION SYSTEM</u> The ignition system consists of a spark plug, high voltage source and hydrogen supply. The spark plug is attached to the appendage on the swirl plate and is contained inside the combustor housing. Connected (via a spring) to a high voltage feedthrough in the top of the combustor housing, the spark plug is wired to a high voltage transformer. Bottled hydrogen is routed into the combustor housing where a 0.32 cm (0.125 in) diameter stainless tube delivers it into the spark plug appendage. The fuel is ignited by a depressing a control switch which activates a time sequence spark plug firing, hydrogen supply and fuel supply. If ignition is not achieved, the fuel and hydrogen valves are closed, the fuel line is automatically purged with nitrogen, and a time delay is initiated before a permissive is satisfied allowing another ignition sequence attempt. Usually the combustor ignites on the first attempt.

CONTROL AND MONITORING SYSTEMS

All transducers, thermocouples and automatic valve controls are wired from their rig locations to a console located in a control room adjacent to the test cell. All systems are monitored by a programmable controller (Modicon) which sequences required permissives through appropriate relay networks (relay ladder logic networks). There are two operating modes to control air flow, fuel flow, system pressure, and quench water flow. They include 1) analog control from the control panel, and 2) digital control from a personal computer. Analog control is used for system checkouts while all test runs are made under computer control.

Critical system permissives are additionally wired to an annunciator panel with visual indication and audio alarm. All system parameters are monitored with analog devices and selected parameters are also monitored and recorded with the computer.

<u>ANALOG CONTROL AND MONITORING</u> Proportional controllers with rate and reset are used to control air flow, fuel flow, system pressure, nitrogen differential pressure and quench water flow. Each of these controllers can be operated in either manual valve control or automatic setpoint control. Manual control involves direct positioning of supply valves. In the automatic mode, a supply valve is regulated such that an input signal (feedback) is matched to a setpoint. Input for the air flow controller is provided by a mass flow rate computer whose inputs are pressure, temperature and differential pressure

across the air line venturi. The fuel flow controller receives input from a mass flow rate indicator coupled with a flow transmitter and temperature sensor. The system pressure, quench water flow, and nitrogen flow controllers receive inputs from a pressure transducer, thermocouple, and differential pressure transducer, respectively.

Analog monitoring is accomplished with analog or digital meters, a two color optical pyrometer, and a video camera, all of which are mounted in the control room console.

COMPUTER CONTROL, MONITORING & DATA ACQUISITION A personal computer is interfaced with a data acquisition and control unit containing both analog input and analog output cards. Critical instrumentation is wired to the analog input cards. Directed by the computer, an internal voltmeter scans the input cards to monitor temperature, pressure, and mass flow rate inputs. Using calibration coefficients, the software converts the input signals and displays the data in either tabular or graphics format as shown in Figures 9a and 9b, respectively. Information such as valve positions, setpoints, and other calculated values (fuel-air ratio, velocity, time) is also displayed on the computer screen.

Control of air flow, fuel flow, quench water flow, and system pressure is maintained with analog output cards which are wired to corresponding electro-pneumatic control valves. Two modes of computer control (direct control of valve position and closed loop control of a specified setpoint) are available for each valve. Valve positions and setpoints may be changed using special function keys defined by the mode selected. Air mass flow rate, fuel-to-air ratio, system pressure, and exit temperature are the parameters available for closed loop control. When selected, rate and reset (PID) subroutines compare the actual data to the setpoint, modifying the valve positions until the setpoint is converged upon. In addition to data monitoring and control, the computer provides automated data acquisition and an electronic logbook. Internal clocks provide "real-time" stamping of data which can be printed and/or stored on a hard disk at user-defined intervals. A run summary (shown in Figure 10) is generated to document simple statistics on test parameters in addition to logged combustion time, fuel usage, and specimen test history. The software (developed by the authors and listed in Appendix A for documentation purposes) also includes subroutines for data plotting.

OPERATIONS

<u>OPERATIONAL MODES</u> The standard mode of operation is to control the fuel-to-air-ratio (f/a) for a fixed air flow rate (m_a) and fixed system pressure (P_s). Both the resultant gas temperature (T_g) and sample temperature (T_s) is thus fixed by the selected f/a, m_a and P_s. The rig typically operates with m_a=0.45 kg/sec (1 lbm/sec). This flow rate was selected to provide adequate cooling to the combustor liner over the entire operating range of the combustor which has broad stability limits. Combustion can be initiated and maintained at equivalence ratios (ϕ) of 0.4 to 2.0 (f/a of 0.025 to 0.135), however

the region around stoichiometric (f/a=0.06-0.1, ϕ=0.9-1.5) is avoided to minimize rig component durability problems. If the f/a selected is such that moderate combustion temperatures are attained, the rig can be run with m_a as low as 0.23 kg/sec (0.5 lb/sec) and still have sufficient cooling for the combustor liner. The system pressure is selected on the basis of the desired combustion product flow velocity in the test section. Stable operation has been achieved for system pressures of 5 to 25 atmospheres (60 to 350 psig) for the range of f/a of interest to the materials test program.

If lower sample temperatures are desired at a selected f/a, an option is available to add a water-cooled transition section between the combustor and test section. (The interior of this section is thermal barrier coated.) With this section in place the associated heat loss results in lowering both the gas and sample temperatures between 200 and 300°C (400-600°F) depending on the particular f/a. By appropriately controlling the cooling water flow through the transition section it may be possible control the heat loss and thus the temperature drop.

<u>HEAT TRANSPORT MECHANISMS</u> The samples under test are heated mainly by convection from the flowing gas but there is also some heating by radiation from the combustor. Radiation heating has been observed by monitoring the test section thermocouple with the samples both withdrawn and inserted. When the samples are inserted the thermocouple yields a lower temperature, possibly because the samples (i.e., 2.5 cm wide samples) block some/all of the radiation from the combustor.

The observed temperature difference depends on the f/a ratio and resultant combustor temperature (at f/a=.06 the temperature drop is about 50°C or 100°F). The samples loose heat by conduction to the holder and by radiation to the relatively cold test section walls. However, under rich-burn conditions the gas is extremely luminous, therefore heat loss by radiation from the samples is assumed to be negligible.

The rig configuration is too complex to reasonably calculate heat transfer coefficients, etc. In addition, the inability to account for radiation heating, radiation cooling, and conductive heat losses make analytical modelling of sample temperatures difficult. As a result, we rely on thermocouple and optical pyrometry measurements to ascertain gas and sample temperatures.

<u>TEMPERATURE MEASUREMENT</u> As noted, a two color optical pyrometer can be sighted through the viewport onto the sample and a video camera can also be sighted on the sample through the pyrometer. When operating in the lean-burn mode the sample's leading edge can readily be seen and its apparent temperature measured with the pyrometer. In the rich-burn mode the sample is not visible because of the intense luminosity of the combustion product gas and therefore sample temperature cannot be measured directly. To circumvent this problem the sample temperature (T_s) is measured via pyrometer, as a function of f/a, in the lean-burn mode, and correlated with the gas temperature (T_g) measured by the test section thermocouple located directly behind the samples. A plot of the respective temperatures versus f/a is shown in

Figure 11 for a Hexoloy (hot-pressed SiC monolithic) sample. The resulting correlation between the pyrometer measured sample temperature and the gas temperature is shown in Figure 12, where a least squares fit of the data was used to obtain an equation relating sample temperature to gas temperature.

This correlation is used to estimate the sample temperature in the rich-burn mode. To deduce sample temperature in the rich-burn mode, it is assumed that the relationship between the sample temperature and the gas temperature, measured in the lean-burn mode, still holds. By measuring the gas temperature in the rich-burn mode the sample temperature can be calculated. Assumptions made in this procedure have not been validated experimentally but appear reasonable since the air mass flow is held constant and the fuel flow is only a small fraction (13.4% at ϕ = 2.0) of the 0.45 kg/sec (1 lbm/sec) air mass flow. The difference in the combustion products composition between the lean and rich modes is expected to make little difference in the heat transfer to the sample except possibly when heavy sooting occurs. Not surprisingly, the calibration curve depends on the sample material and size as well as on the sample holder material (insulator vs superalloy). Therefore a separate calibration curve is determined for each material tested.

At this point, it is helpful to discuss both the factors which influence temperature measurement with a two color optical pyrometer and the errors which may be present in the data collected. When measuring sample temperatures one must be aware that sample emissivity is still a dominant factor to be considered! The pyrometer sensor operates by comparing the radiation detected at two wavelengths and computing the ratio. If the sample's emissivity characteristics are independent of wavelength, for the two wavelengths measured, then the measured temperature is correct. However, if there is a wavelength dependence of emissivity the ratio of the two detected signals would be weighted incorrectly and a temperature error would result. The two color pyrometer has a slope adjustment to compensate for the slope in the emissivity versus wavelength curve. If the sample temperature is independently known the proper slope setting can be ascertained and set to yield correct temperatures.

In our situation the sample temperature in <u>not</u> independently known. In practice we set the slope adjustment to the greybody position which is correct for clean unoxidized SiC. In reality though the SiC sample grows a SiO_2 scale (at least under lean-burn conditions). This scale changes the emissivity of the sample and we have evidence that the emissivity of SiO_2 is not wavelength independent over the range of wavelengths used by the pyrometer. Thus the greybody slope setting is no longer valid; the pyrometer temperatures we record have an uncertainty associated with them. The magnitude of this uncertainty is at present unknown and we are still addressing this problem.

PERFORMANCE

<u>TESTING</u> Combustion gas temperatures measured with the thermocouple are

shown as a function of f/a in Figure 13 for both the lean and rich-burn modes together with the calculated adiabatic temperature. This data was obtained by varying the f/a for a fixed m_a and P_s. The gas temperature curve excludes data within stoichiometric range and is expected to have a higher apex. As noted, operation in this range of higher temperatures is avoided for rig component durability reasons. At any fixed f/a the gas temperature variation with time for short time intervals, e.g. 1.5 hrs, is only near ± 8°C (± 14°F) as shown in Figure 14. Note, the corresponding sample temperature variation measured directly from a C/SiC (carbon reinforced silicon carbide) composite during lean-burn operation is even less at ± 5°C (± 9°F). However, on the basis of the limited data now available it has been observed that during time intervals of 50-100 hrs, at fixed f/a, the temperature gradually drifts and the variation increases. Many variables (test cell temperature, compressor discharge temperature, metal temperatures) are different at startup as opposed to extended running and may in part account for the drift.

Figure 15 shows some typical data obtained during the rich-burn testing of the C/SiC composite samples. The x-axis is time and the y-axis is the sample temperature as calculated from the gas temperature correlation data. Here, the temperature varies about ± 22°C (40°F) suggesting that the gas temperature variation increases slightly during rich-burn operation. The long term drift also contributes to the increased variation. However, it is believed that the sample temperature does not actually vary this much (Figure 14) because its thermal mass is much greater than that of the gas temperature measurement thermocouple. From Figure 15 one obtains an average temperature of 1373°C (2503°F) that represents the sample exposure test conditions to an estimated ± 16°C (30°F).

<u>RIG DURABILITY</u> The combustor components have shown excellent durability over the first 300 hours of operation with over 150 ignition cycles. No distortion of the liner has been observed and the thermal barrier coating on its interior has remained perfectly intact. At 4 inspection intervals in the 300 hours some very slight soot accumulation in the combustor liner has been noted. The accumulation is very friable and easily brushed away. No clogging of the fuel nozzle has been observed and the swirller is almost pristine. Thermocouple life had proven to be a major durability problem, but through experience has lead to improved designs and a systematic change schedule has been established. The sample holder shows no distress after 300 hours. The lava sample support blocks have shown some degradation, however they did function satisfactorily during 50 hrs of exposure (T_g=1500°C or 2725°F) of rich-burn (f/a=1.8) operation using Hexoloy samples. In a 50 hr test with the C/SiC samples the lava blocks had undergone such severe degradation that they had to be changed several times. It is believed that with these samples the heat transfer to the lava blocks was sufficiently increased to account for the degradation. Substituting superalloy blocks for the lava has proven to be a viable alternative.

CONCLUDING REMARKS

The high pressure burner rig at Lewis Research Center has been successfully modified to be a lean- or rich-burn materials test facility. The preferred range of fuel-to-air ratios is from 0.025 to 0.060 (ϕ=0.4 to 0.9) for lean-burn operation and 0.100 to 0.135 (ϕ=1.5 to 2.0) for rich-burn operation. Fuel-to-air ratios in the high temperature region (ϕ=0.9 to 1.5) near stoichiometric are avoided so as not to exacerbate rig component durability problems. Apparent sample temperatures as high as 1550°C (2800°F) can be obtained while still avoiding the stoichiometric region.

Three sample materials (Hexoloy, Carbon reinforced SiC, and SiC reinforced SiC) have been successfully tested for 50 hr. each in a rich-burn (ϕ=1.8) combustion environment.

Accurate determination of true sample temperatures in the test rig is still a formidable problem and the subject of ongoing efforts. However we feel that the temperatures we report are sufficiently accurate for materials test purposes and the temperature variability certainly is within the limits expected for aero engine combustors.

While the rig has demonstrated satisfactory durability, opportunities for improvement continually present themselves and these are being pursued iteratively while conducting the materials test program.

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APPENDIX A

The software listed on the following pages has been included to serve as documentation of the control and operational procedures used in this facility. As seen before, facilities such as these may experience periods of dormancy due to programmatic or personnel changes. In such a case, this record could prove critical in attempts to renew operations to the facility after any such period.

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10 ! PROGRAM "X6_SHORT"
20 ! HIGH PRESSURE BURNER RIG - DATA AQUISITION AND CONTROL
30 ! LAST REVISION 10/93 ; C.ROBINSON ; X-5547
40     OPTION BASE 1
50     DIM Chan_label$(40)[16],Display_format$(40)[5],Sensor$(40)[5],Test$[15]
60     DIM Unit$(40)[4],Suffix$(10)[1],Disp$(15)[68],Parm$(10)[15]
70     DIM Specimen$(2)[15],Install$(2)[15],Spec_info$(2)[80]
80     DIM L1$[1],L4$[4],L5$[5],L6$[6],L8$[8],Part1_disp$[32],Part2_disp$[32]
90     DIM Ans$[80],Blank$[80],File_name$[15],Image$[80],Template$[15]
100    DIM Screen(15,2),Cox(5),Tstart(3),Trich(2),Tlean(2),Stat(4,10)
110    DIM Volt(30),Dval(40),Kref(13),Rref(13),R(13),Hi_lim(40),Low_lim(40)
120    DIM P(7,5),Amt(5),P_prop(5),Ignite_sp(4),Stor_buf(13,500),Array(13,500)
130    REAL Vref,Volt_comp,Vt,Temp,Err,Out,Prop,Sp_fraction,Bytes,Fuel_lbs
140    REAL Air_flow_sp,Fa_ratio_sp,Sys_psi_sp,Setpoint,Fuel_sp,Air_sp
150    REAL Ts,Trun,Tcomb,Tinsert,Tretract,Tloop,Quench_sp,Back_sp
160    INTEGER I,J,N,X,Y,Data_pts,Pid,Prt_int
170    INTEGER Print_order(11),Cycles(6),Life_cycles,Control_ind(3),Flag(10)
180    INTEGER Airout,Backout,Quenchout,Fuelout
190    PRINTER IS 1
200    DUMP DEVICE IS 26
210    CLEAR SCREEN
220    PLOTTER IS CRT,"INTERNAL";COLOR MAP
230    SET PEN 0 INTENSITY 0,0,.45
240    PRINT TABXY(1,27);DATE$(TIMEDATE)&"...."&TIME$(TIMEDATE)
250    LINPUT "IS THIS THE CORRECT TIME AND DATE? (Y/N)",Ans$
260    PRINT TABXY(1,27);"                                              "
270    IF Ans$="Y" OR Ans$="y" THEN GOTO 300
280    LINPUT "ENTER TODAY'S DATE & TIME (08 JUL 1991 09:45:30)",Ans$
290    SET TIMEDATE DATE(Ans$[1,11])+TIME(Ans$[13,20])
300 Main_menu_keys:  !
310    ON KEY 1 LABEL "RUN RIG ",10 GOTO Main
320    ON KEY 2 LABEL "        ",10 GOSUB Invalid
330    ON KEY 3 LABEL " TEST    SETUP  ",10 GOTO Setup
340    ON KEY 4 LABEL "        ",10 GOSUB Invalid
350    ON KEY 5 LABEL " CREATE   DOS   ",10 GOTO Create_ascii
360    ON KEY 6 LABEL "        ",10 GOSUB Invalid
370    ON KEY 7 LABEL "PRINTOUT",10 GOTO Printout
380    ON KEY 8 LABEL "  PLOT  ",10 GOTO Plot
390 Menu_display:  !
400    PRINT TABXY(2,1)
410    PRINT "         HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG"
420    PRINT
430    PRINT
440    PRINT "                              OPTION MENU                 "
450    PRINT
460    PRINT "                   F1: DATA ACQ. AND CONTROL PGM          "
470    PRINT
480    PRINT "                   F3: EDIT TEST SETUP                    "
490    PRINT
500    PRINT "                   F5: CREATE DOS FILE (from BDAT) FOR "
510    PRINT "                       MATLAB, SIGMAPLOT, & OTHER USES "
520    PRINT
530    PRINT "                   F7: PRINT CONTENTS OF A DATA FILE   "
540    PRINT
550    PRINT "                   F8: PLOTTING ROUTINE                   "
560    DISP "CHOOSE OPTION USING FUNCTION KEYS"
570    KEY LABELS ON
580 Echo:  !
590    GOTO Echo
```

```
600 Printout:  !
610    MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
620    CLEAR SCREEN
630    CAT;NAMES
640    LINPUT "ENTER FILENAME TO PRINT OR 0=QUIT",File_name$
650    IF File_name$="0" THEN
660      CLEAR SCREEN
670      GOTO Menu_display
680    ELSE
690      GOSUB Read_bdat
700      GOSUB Tabulate
710      GOTO 640
720    END IF
730 Read_bdat:   !
740    ASSIGN @Path_1 TO File_name$
750    ENTER @Path_1;File_name$,Data_pts
760    FOR I=3 TO 13
770      ENTER @Path_1;Chan_label$(I),Display_format$(I)
780    NEXT I
790    MAT Array= Stor_buf(1:13,1:Data_pts)
800    ENTER @Path_1;Array(*)
810    ASSIGN @Path_1 TO *
820    Chan_label$(1)="DATA PT.        "
830    Chan_label$(2)="TIME (HRS)      "
840    Display_format$(1)="DDD"
850    Display_format$(2)="DD.DD"
860    RETURN
870 Create_ascii:   !
880    CLEAR SCREEN
890    MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
900    CAT;NAMES
910    LINPUT "ENTER FILENAME OF DATA TO BE CONVERTED TO DOS",File_name$
920    GOSUB Read_bdat
930    Bytes=8*Data_pts+20*Data_pts+10*11*Data_pts
940    Bytes=INT(Bytes/256)+1
950    MASS STORAGE IS "\BLP\PGMS:DOS,C"
960    CREATE ASCII "XXXXXXXX",Bytes
970    ASSIGN @Path_1 TO "XXXXXXXX"
980    OUTPUT @Path_1;Array(*)
990    ASSIGN @Path_1 TO *
1000   LOAD "ASCI2DOS",10
1010 Tabulate:   !
1020   PRINTER IS 26
1030   PRINT "DATA RETRIEVED FROM FILE: \BLP\X6_BDATS\",File_name$,":DOS,C"
1040   PRINT "TOTAL DATA PTS: ",Data_pts
1050   PRINT
1060   FOR I=1 TO 13
1070     PRINT USING "2D,2A,16A";I,". ",Chan_label$(I)
1080   NEXT I
1090   PRINT
1100   PRINT "  1   2     3     4     5     6     7     8     9    10    11    1
2    13   "
1110   PRINT
1120   FOR J=1 TO Data_pts
1130     FOR I=1 TO 13
1140       PRINT USING Display_format$(I)&",X,#";Array(I,J)
1150     NEXT I
1160     PRINT
1170   NEXT J
1180   PRINT CHR$(12)
```

```
1190   PRINTER IS 1
1200   RETURN
1210 Plot:  !
1220   MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
1230   PLOTTER IS CRT,"INTERNAL";COLOR MAP
1240   SET PEN 0 INTENSITY 0,0,.45
1250   CLEAR SCREEN
1260   CAT;NAMES
1270   LINPUT "ENTER FILENAME OF DATA TO BE PLOTTED",File_name$
1280   GOSUB Read_bdat
1290   GOSUB X_parm
1300   GOSUB Y_parm
1310   GOSUB Create_plot
1320   ON KEY 1 LABEL " CHANGE  X-PARM ",10 GOSUB X_parm
1330   ON KEY 2 LABEL " CHANGE  Y-PARM ",10 GOSUB Y_parm
1340   ON KEY 3 LABEL "SCALE XY",10 GOSUB Scale_xy
1350   ON KEY 4 LABEL "  PLOT  ",10 GOSUB Create_plot
1360   ON KEY 5 LABEL "NEW DATA",10 GOTO Plot
1370   ON KEY 6 LABEL " TITLE  ",10 GOSUB Plot_label
1380   ON KEY 7 LABEL "  DUMP  ",10 GOSUB Dump
1390   ON KEY 8 LABEL "  EXIT  ",10 GOTO Review
1400 Hold:  !
1410   GOTO Hold
1420 Dump:  !
1430   DUMP GRAPHICS
1440   PRINTER IS 26
1450   PRINT CHR$(12)
1460   PRINTER IS 1
1470   RETURN
1480 Plot_label:  !
1490   LINPUT "ENTER NEW PLOT TITLE (50 CHARACTERS MAX)",Ans$
1500   GOSUB Create_plot
1510   RETURN
1520 X_parm:  !
1530   GOSUB Plot_variables
1540   INPUT "ENTER INDEX OF X PARAMETER",X
1550   INPUT "ENTER XMIN",Xmin
1560   INPUT "ENTER XMAX",Xmax
1570   Xdelta=(Xmax-Xmin)/11
1580   DISP "CHOOSE NEXT OPTION USING FUNCTION KEYS"
1590   RETURN
1600 Scale_xy:  !
1610   LINPUT "SCALE X OR Y?",Ans$
1620   DISP Blank$
1630   IF Ans$="X" THEN
1640     INPUT "ENTER XMIN",Xmin
1650     INPUT "ENTER XDELTA",Xdelta
1660   END IF
1670   IF Ans$="Y" THEN
1680     INPUT "ENTER YMIN",Ymin
1690     INPUT "ENTER YDELTA",Ydelta
1700   END IF
1710   GOSUB Create_plot
1720   RETURN
1730 Y_parm:  !
1740   GOSUB Plot_variables
1750   INPUT "ENTER INDEX OF Y PARAMETER",Y
1760   INPUT "ENTER YMIN",Ymin
1770   INPUT "ENTER YMAX",Ymax
1780   Ydelta=(Ymax-Ymin)/7
```

```
1790   DISP "CHOOSE NEXT OPTION USING FUNCTION KEYS"
1800   RETURN
1810 Plot_variables:  !
1820   CLEAR SCREEN
1830   PRINT "CHOOSE PLOT PARAMETERS"
1840   PRINT
1850   FOR I=1 TO 13
1860     PRINT USING "DD,2A,16A";I,". ",Chan_label$(I)
1870   NEXT I
1880   RETURN
1890 Create_plot:    !
1900   CLEAR SCREEN
1910   GINIT
1920   CLIP 15,125,20,90
1930   AXES 2,2,15,20,5,5,3
1940   CLIP OFF
1950   CSIZE 2.8
1960   ! SCALE X AXIS
1970   MOVE 10,15
1980   OUTPUT L5$ USING Display_format$(X)&",#";Xmin
1990   LABEL L5$[1,5]
2000   FOR I=1 TO 5
2010     MOVE 10+I*20,15
2020     OUTPUT L5$ USING Display_format$(X)&",#";Xmin+Xdelta*2*I
2030     LABEL L5$[1,5]
2040   NEXT I
2050   ! SCALE Y AXIS
2060   MOVE 6,19
2070   OUTPUT L5$ USING Display_format$(Y)&",#";Ymin
2080   LABEL L5$[1,5]
2090   FOR I=1 TO 7
2100     MOVE 6,I*10+19
2110     OUTPUT L5$ USING Display_format$(Y)&",#";Ymin+Ydelta*I
2120     LABEL L5$[1,5]
2130   NEXT I
2140   ! LABEL X-Y AXIS
2150   MOVE 55,10
2160   CSIZE 3.5
2170   LABEL Chan_label$(X)
2180   MOVE 3,40
2190   LDIR 89.53
2200   LABEL Chan_label$(Y)
2210   ! TITLE & FOOTNOTES
2220   LDIR 0
2230   MOVE 10,97
2240   LABEL USING "8A,3A,50A";File_name$," : ",Ans$[1,50]
2250   MOVE 0,7.5
2260   CSIZE 2.0
2270   OUTPUT L8$ USING "DDDD.DDD,#";Xdelta
2280   LABEL USING "7A,8A";"XDELTA=",L8$
2290   MOVE 20,7.5
2300   OUTPUT L8$ USING "DDDD.DDD,#";Ydelta
2310   LABEL USING "7A,8A";"YDELTA=",L8$
2320   ! DATA POINTS
2330   VIEWPORT 15,125,20,90
2340   WINDOW Xmin,Xmin+Xdelta*11,Ymin,Ymin+Ydelta*7
2350   FOR I=1 TO Data_pts
2360     MOVE Array(X,I),Array(Y,I)
2370     PLOT Array(X,I),Array(Y,I)
2380   NEXT I
```

```
2390   RETURN
2400 Setup: !
2410   MASS STORAGE IS "\BLP\PGMS:DOS,C"
2420   GOSUB Read_common
2430   KEY LABELS OFF
2440   CLEAR SCREEN
2450   PRINT "TEST: ",Test$
2460   PRINT
2470   PRINT USING 2490;"Time on combustor (hrs):",Tcomb
2480   PRINT USING 2490;"Total number of  cycles:",Life_cycles
2490   IMAGE 24A,4D.D
2500   PRINT
2510   PRINT "AIR FLOW : "&Parm$(1)
2520   PRINT "FA RATIO : "&Parm$(2)
2530   PRINT "PRESSURE : "&Parm$(3)
2540   PRINT "VELOCITY : "&Parm$(4)
2550   PRINT "GAS TEMP : "&Parm$(5)
2560   PRINT "SRF TEMP : "&Parm$(6)
2570   PRINT
2580   GOSUB Spec_info
2590   INPUT "ENTER INDEX: (1=HRS/CYC 2=TEST DATA 3=SPEC DATA 0=QUIT)",I
2600   SELECT I
2610   CASE 1
2620     INPUT "ENTER NEW COMBUSTOR TIME ",Tcomb
2630     INPUT "ENTER NEW TOTAL # CYCLES ",Life_cycles
2640     GOTO 2440
2650   CASE 2
2660     INPUT "ENTER NEW TEST #",Test$
2670     INPUT "ENTER NEW AIR FLOW TARGET",Parm$(1)
2680     INPUT "ENTER NEW F/A RATIO TARGET",Parm$(2)
2690     INPUT "ENTER NEW PRESSURE TARGET",Parm$(3)
2700     INPUT "ENTER NEW GAS VELOCITY TARGET",Parm$(4)
2710     INPUT "ENTER NEW GAS TEMPERATURE",Parm$(5)
2720     INPUT "ENTER NEW SRF TEMPERATURE",Parm$(6)
2730     GOTO 2440
2740   CASE 3
2750     INPUT "ENTER POSITION TO BE EDITED (1=TOP,2=BOT)",J
2760     LINPUT "ENTER SPECIMEN ID (8 CHARACTERS MAX) OR -1 FOR NO CHANGE",Ans$
2770     IF Ans$="-1" THEN GOTO 2790
2780     Specimen$(J)=Ans$
2790     LINPUT "ENTER DATE INSTALLED (DD MMM YYYY) OR -1 FOR NO CHANGE",Ans$
2800     IF Ans$="-1" THEN GOTO 2820
2810     Install$(J)=Ans$
2820     INPUT "ENTER NUMBER OF CYCLES COMPLETE",Cycles(J)
2830     INPUT "ENTER LEAN TIME (HRS) TO DATE",Tlean(J)
2840     INPUT "ENTER RICH TIME (HRS) TO DATE",Trich(J)
2850     LINPUT "ENTER SPECIMEN NOTES (1 line max) OR -1 FOR NO CHANGE",Ans$
2860     IF Ans$="-1" THEN GOTO 2440
2870     Spec_info$(J)=Ans$
2880     GOTO 2440
2890   CASE 0
2900     GOSUB Write_common
2910     CLEAR SCREEN
2920     GOTO Main_menu_keys
2930   CASE ELSE
2940     GOTO 2440
2950   END SELECT
2960 Spec_info:  !
2970   PRINT "                    ................SPECIMEN HISTORY..............."
2980   PRINT
```

```
2990   PRINT USING 3020;"POSITION","SPECIMEN","INSTALLED","CYCLES","LEAN HRS.","
RICH HRS."
3000   PRINT USING 3030;"TOP",Specimen$(1),Install$(1),Cycles(1),Tlean(1),Trich(
1)
3010   PRINT USING 3030;"BOT",Specimen$(2),Install$(2),Cycles(2),Tlean(2),Trich(
2)
3020   IMAGE 8A,5X,8A,5X,9A,5X,6A,5X,9A,5X,9A
3030   IMAGE 2X,3A,8X,10A,2X,11A,6X,3D,6X,3D.D,10X,3D.D
3040   PRINT
3050   PRINT "TOP: "&Spec_info$(1)
3060   PRINT "BOT: "&Spec_info$(2)
3070   RETURN
3080 Spec_update:!  UPDATE ACCUMULATIVE HOT TIMES
3090   Tcomb=Tcomb+Trun/3600
3100   IF Flag(5)=0 THEN
3110     Tlean(1)=Tlean(1)+Tinsert/3600
3120     Tlean(2)=Tlean(2)+Tinsert/3600
3130   ELSE
3140     Trich(1)=Trich(1)+Tinsert/3600
3150     Trich(2)=Trich(2)+Tinsert/3600
3160   END IF
3170   RETURN
3180 Main: !
3190   MASS STORAGE IS "\BLP\PGMS:DOS,C"
3200   KEY LABELS OFF
3210   GOSUB Read_coef
3220   GOSUB Read_label_lim
3230   GOSUB Read_common
3240   GOSUB Read_pid_val
3250   GOSUB Read_suffix
3260   GOSUB Screen_setup
3270   GOSUB Build_string
3280   GOSUB Print_header_1
3290 Init_variables:  !
3300   CLEAR SCREEN
3310   Prt_int=-1
3320   Fa_ratio_sp=-.999
3330   Air_flow_sp=-9.99
3340   Sys_psi_sp=-999.
3350   Blank$="
          "
3360   Data_pts=0
3370   Trun=0.
3380   Tinsert=0.
3390   Tretract=0.
3400   Fuel_lbs=0.
3410   MAT Flag= (0.)
3420   MAT Control_ind= (0.)
3430   MAT Volt= (0.)
3440   MAT Dval= (0.)
3450   MAT Stor_buf= (0.)
3460   MAT Cox= (0.)
3470   MAT Stat= (0.)
3480 Soft_keys: !
3490   CLEAR SCREEN
3500   ON KEY 1 LABEL " FORCED SHUTDOWN",10 GOTO Shutdown
3510   ON KEY 5 LABEL " %  AIR  VALVE",10 GOTO Air_out_sp
3520   ON KEY 3 LABEL "GRAPHIC DISPLAY",10 GOTO Set_display
3530   ON KEY 4 LABEL " MANUAL   DATA  ",10 GOSUB Man_prt_stor
3540   ON KEY 6 LABEL "PREVIOUSLIGHTOFF",10 GOSUB Ignite_sp
```

```
3550   ON KEY 9 LABEL "          ",10 GOSUB Invalid
3560   ON KEY 7 LABEL " % BACK  VALVE",10 GOTO Back_out_sp
3570   ON KEY 8 LABEL " %  H20  VALVE",10 GOTO Quench_out_sp
3580   ON KEY 2 LABEL "CONTROL SETUP",10 GOTO Control_setup
3590   ON KEY 10 LABEL "        ",10 GOSUB Invalid
3600   ON KEY 11 LABEL "        ",10 GOSUB Invalid
3610   ON KEY 12 LABEL "INTERVAL",10 GOTO Set_prt_int
3620   ON KEY 13 LABEL "        ",10 GOSUB Invalid
3630   ON KEY 14 LABEL "        ",10 GOSUB Invalid
3640   ON KEY 15 LABEL "        ",10 GOSUB Invalid
3650   ON KEY 16 LABEL "        ",10 GOSUB Invalid
3660 Init_scanner: !
3670   OUTPUT 709;"AF8AL30AC8VT4VN23VA0VS1VD5SD0AE1"
3680   OUTPUT 709;"VT3"
3690   Tstart(3)=TIMEDATE
3700   Ts=TIMEDATE
3710 Scan: !
3720   Tloop=TIMEDATE-Ts
3730   Ts=TIMEDATE
3740   OUTPUT 709;"VS"
3750   SYSTEM PRIORITY 15
3760   FOR I=1 TO 23
3770     ENTER 709 USING "#,K";Volt(I)
3780   NEXT I
3790   SYSTEM PRIORITY 9
3800   OUTPUT 709;"VT3"
3810   GOSUB Convert
3820   GOSUB Calculate
3830   GOSUB Check
3840   GOSUB Control
3850   GOSUB Status
3860   GOSUB Display
3870   OUTPUT 709;"AO3,0,"&VAL$(INT(Dval(24)*2000))
3880   OUTPUT 709;"AO4,1,"&VAL$(INT(Dval(25)/1000*2000))
3890   IF Flag(1)=1 THEN Fuel_lbs=Fuel_lbs+Dval(16)*Tloop/3600
3900   IF Prt_int=-1 THEN GOTO 3950
3910   IF TIMEDATE-Tstart(3)>Prt_int THEN
3920     Tstart(3)=TIMEDATE
3930     GOSUB Man_prt_stor
3940   END IF
3950   GOTO Scan
3960 Convert:  !
3970   Vref=Volt(12)
3980 Type_k:  !
3990   FOR J=1 TO 13
4000     R(J)=Kref(J)
4010   NEXT J
4020   Volt_comp=R(1)+Vref*(R(2)+Vref*R(3))
4030   FOR I=1 TO 5
4040     Vt=Volt_comp+Volt(I)
4050     GOSUB Temp_calc
4060   NEXT I
4070   FOR I=10 TO 11
4080     Vt=Volt_comp+Volt(I)
4090     GOSUB Temp_calc
4100   NEXT I
4110 Type_r:  !
4120   FOR J=1 TO 13
4130     R(J)=Rref(J)
4140   NEXT J
```

```
4150   Volt_comp=R(1)+Vref*(R(2)+Vref*R(3))
4160   FOR I=6 TO 9
4170     Vt=Volt_comp+Volt(I)
4180     Vt=Vt*1.E+6
4190     GOSUB Temp_calc
4200   NEXT I
4210   ! AC051 - Pyrometer : 0-5 volts = 1800-3200 F
4220!  Dval(14)=(Volt(14)*14000+1800)
4230   ! AC051 - Pyrometer correlation with TC probe
4240!  Dval(14)=Dval(8)*.826+298.2     ! FOR HEXALOY IN LAVA
4250   Dval(14)=Dval(8)*.864+153.7     ! FOR BF GOODRICH SiC/SiC IN LAVA
4260   ! AC008 - Daniels Airflow : 0-5 volts = 0-2 pps
4270   Dval(15)=Volt(15)*.40
4280   ! FC227 - Fuel Flow (coxmeter) : 0-1200 Hz = 0-2.5 GPM
4290   Dval(16)=Volt(16)*400/2.5              ! (DC to Hz, 800 Hz fs, cal=50%)
4300   Dval(16)=Dval(16)*.0020261-.0001078    ! (Hz to GPM)
4310   Dval(16)=Dval(16)*60*6.74              ! (GPM to #/HR)
4320   FOR I=1 TO 4
4330     Cox(I)=Cox(I+1)
4340   NEXT I
4350   Cox(5)=Dval(16)
4360   Dval(16)=(Cox(1)+Cox(2)+Cox(3)+Cox(4)+Cox(5))/5
4370   ! WS075 - H2O Flow
4380   Dval(17)=Volt(17)*400/2.5              ! (DC TO Hz, 800 Hz fs, CAL=50%)
4390   Dval(17)=Dval(17)*.02565-.023895       ! (Hz TO GPM)
4400   ! FC219 - Fuel Flow
4410   Dval(18)=Volt(18)*125.-125.
4420   ! AC040 - Nitrogen Press
4430   Dval(19)=Volt(19)*1000./5.
4440   ! FC223 - Fuel Press
4450   Dval(20)=(-.026+20.0*Volt(20))*1000./100.
4460   ! AC090 - Preheat Press
4470   Dval(21)=Volt(21)*1000./5.0
4480   ! AC050 - Viewport Press
4490   Dval(22)=Volt(22)*836.0/4.186
4500   ! AC091 - Test Sect Press
4510   Dval(23)=Volt(23)*831.2/4.1643
4520   RETURN
4530 Temp_calc:  !
4540   Temp=R(8)+Vt*(R(9)+Vt*(R(10)+Vt*(R(11)+Vt*(R(12)+Vt*(R(13))))))
4550   Temp=R(4)+Vt*(R(5)+Vt*(R(6)+Vt*(R(7)+Vt*Temp)))
4560   Dval(I)=Temp*1.8+32
4570   RETURN
4580 Check:  !
4590   FOR I=1 TO 33
4600     IF Dval(I)<Low_lim(I) THEN Dval(I)=Low_lim(I)
4610     IF Dval(I)>Hi_lim(I) THEN
4620       SELECT Display_format$(I)
4630       CASE "DDD.D"
4640         Dval(I)=999.9
4650       CASE "DD.DD"
4660         Dval(I)=99.99
4670       CASE ELSE
4680         Dval(I)=9999.
4690       END SELECT
4700     ELSE
4710       GOTO 4730
4720     END IF
4730   NEXT I
4740   RETURN
```

```
4750 Calculate:  !
4760   IF Dval(15)=0. THEN
4770     Dval(24)=0.
4780   ELSE
4790     Dval(24)=Dval(16)/(Dval(15)*3600)
4800   END IF
4810   Dval(25)=1.85*Dval(15)*(Dval(8)+460)/(Dval(23)+14.7)
4820   Dval(26)=Fuel_sp
4830   Dval(27)=Air_sp
4840   Dval(28)=Quench_sp
4850   Dval(29)=Back_sp
4860   Dval(30)=Fa_ratio_sp
4870   Dval(31)=Air_flow_sp
4880   Dval(32)=Sys_psi_sp
4890   Dval(33)=Dval(24)/.067
4900 Status:  !
4910   IF Dval(8)>800 OR Dval(6)>800 THEN
4920     SELECT Flag(1)
4930     CASE 0
4940       GOSUB Light_off
4950     CASE 1
4960       GOSUB Run_time
4970     CASE ELSE
4980       GOTO 5080
4990     END SELECT
5000   ELSE
5010     IF Flag(1)=1 THEN
5020       PRINTER IS 701
5030       PRINT USING 5040;TIME$(TIMEDATE),"FLAMEOUT DETECTED FROM COMB TEMP!"
5040       IMAGE 8A,2X,33A
5050       GOSUB Cooldown
5060       IF Flag(4)=1 THEN GOSUB Retract
5070     END IF
5080   END IF
5090   RETURN
5100 Run_time:  !
5110   Trun=TIMEDATE-Tstart(1)
5120   IF Volt(13)>12. THEN
5130     SELECT Flag(4)
5140     CASE 0
5150       GOSUB Insert
5160     CASE 1
5170       Tinsert=Tretract+(TIMEDATE-Tstart(2))
5180     END SELECT
5190   ELSE
5200     IF Flag(4)=1 THEN GOSUB Retract
5210   END IF
5220   RETURN
5230 Display:  !
5240   IF Flag(6)=0 THEN
5250     GOSUB Modify_string
5260     IF Flag(2)=0 THEN
5270       CLEAR SCREEN
5280       PRINT "           HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER
RIG           "
5290       PRINT
5300       PRINT USING "30X,11A";DATE$(TIMEDATE)
5310       PRINT
5320       FOR I=1 TO 15
5330         PRINT TABXY(7,I+7);Disp$(I)[1,32]
```

```
5340         PRINT TABXY(43,I+7);Disp$(I)[37,68]
5350       NEXT I
5360       Flag(2)=1
5370       KEY LABELS ON
5380     ELSE
5390       FOR I=1 TO 15
5400         PRINT TABXY(29,I+7);Disp$(I)[23,27]
5410         PRINT TABXY(65,I+7);Disp$(I)[59,63]
5420       NEXT I
5430     END IF
5440   ELSE
5450     GOSUB Illustrate
5460   END IF
5470   IF Flag(1)=1 THEN
5480     DISP USING "9A,DD.D";"RUN TIME:",Trun/3600
5490   END IF
5500   RETURN
5510 Illustrate:  !
5520   IF Flag(3)=0 THEN
5530     CLEAR SCREEN
5540     PEN 1
5550     LINE TYPE 1
5560     ! MAIN OUTLINE
5570     MOVE 5,65
5580     RESTORE 5660
5590     J=6
5600     GOSUB Read_draw_xy
5610     MOVE 50,75
5620     J=17
5630     GOSUB Read_draw_xy
5640     MOVE 75,70
5650     RECTANGLE 11,10
5660     DATA 10,65,15,62.5,25,62.5,35,65,45,65,45,75
5670     DATA 50,65,77.5,65,77.5,70,82.5,70,82.5,65,120,65,125,60
5680     DATA 140,60,140,45,125,45,120,40,35,40,25,42.5,15,42.5,10,40,5,40,5,65
5690     ! BURNER CAN
5700     LINE TYPE 5
5710     MOVE 55,65
5720     J=3
5730     GOSUB Read_draw_xy
5740     MOVE 25,50
5750     J=3
5760     GOSUB Read_draw_xy
5770     DATA 55,60,25,60,25,55,25,45,55,45,55,40
5780     ! FUEL NOZZLE
5790     MOVE 17.5,42.5
5800     J=6
5810     GOSUB Read_draw_xy
5820     DATA 17.5,45,22.5,54,27.5,54,27.5,51,22.5,51,22.5,42.5
5830     ! H2O NOZZLE
5840     MOVE 105,40
5850     J=6
5860     GOSUB Read_draw_xy
5870     DATA 105,45,110,54,115,54,115,51,110,51,110,40
5880     ! TURBULATOR
5890     J=2
5900     GOSUB Move_draw_xy
5910     DATA 100,65,100,55,100,50,100,40
5920     ! SPECIMEN
5930     AREA PEN 2
```

```
5940      MOVE 78,50
5950      RECTANGLE 5,5,FILL
5960      ! AIR SYSTEM
5970      PEN 5
5980      MOVE 37.5,80
5990      DRAW 47.5,80
6000      DRAW 47.5,62.5
6010      ! H2O SYSTEM
6020      J=4
6030      GOSUB Move_draw_xy
6040      DATA 107.5,42.5,107.5,25,117.5,51,125,49,117.5,52.5,127.5,52.5,117.5,54
,125,56
6050      ! FUEL SYSTEM
6060      PEN 2
6070      J=4
6080      GOSUB Move_draw_xy
6090      DATA 20,45,20,25,30,51,37.5,49,30,52.5,40,52.5,30,54,37.5,56
6100      ! PYROMETER
6110      MOVE 87.5,84
6120      DRAW 80.5,84
6130      DRAW 80.5,57.5
6140      GOSUB Template
6150      GOSUB Overlay_num
6160      Flag(3)=1
6170      KEY LABELS ON
6180    ELSE
6190      GOSUB Overlay_num
6200    END IF
6210    RETURN
6220 Read_draw_xy:  !
6230    FOR I=1 TO J
6240      READ X,Y
6250      DRAW X,Y
6260    NEXT I
6270    RETURN
6280 Move_draw_xy:  !
6290    FOR I=1 TO J
6300      READ X,Y
6310      MOVE X,Y
6320      READ X,Y
6330      DRAW X,Y
6340    NEXT I
6350    RETURN
6360 Template:  !
6370    PRINT "          HIGH PRESSURE RICH/LEAN BURN MATERIALS TEST BURNER RIG"
6380    PRINT
6390    PRINT USING "30X,11A";DATE$(TIMEDATE)
6400    RESTORE 6450
6410    FOR I=1 TO 20
6420      READ X,Y,Template$
6430      PRINT TABXY(X,Y);Template$
6440    NEXT I
6450    DATA 55,6,"PYRO:       F",52,17,"      F",10,7," AIR  SYSTEM"
6460    DATA 10,8,"      LB/SEC",10,9,"      F",5,15,"      PSIG"
6470    DATA 5,16,"      F",25,16,"F/A:",25,18,"Phi:",36,15,"      F"
6480    DATA 36,17,"      F",65,14,"      F",47,10,"PSIG",56,15,"FT/S"
6490    DATA 56,20,"PSIG",15,24,"FUEL SYSTEM",15,25,"      LB/HR"
6500    DATA 67,24,"H2O SYSTEM",67,25,"       GPM",36,19,"      F"
6510    RETURN
6520 Overlay_num:  !
```

```
6530    RESTORE 6590
6540    FOR I=1 TO 17
6550      READ J,X,Y
6560      OUTPUT L5$ USING Display_format$(J)&",#";Dval(J)
6570      PRINT TABXY(X,Y);L5$
6580    NEXT I
6590    DATA 15,10,8,3,10,9,18,15,25,6,36,15,7,36,17,23,55,19,33,30,18
6600    DATA 25,55,14,1,65,14,21,5,15,24,30,16,14,61,6,17,68,25,22,46,9
6610    DATA 8,52,17,5,5,16,9,36,19
6620    RETURN
6630 Control:  !
6640 Fuel:  !
6650    IF Control_ind(2)=0 THEN GOTO Air
6660    IF Dval(24)=0. OR Dval(24)=9.999 THEN
6670      PRINTER IS 701
6680      PRINT USING "8A,2X,56A";TIME$(TIMEDATE),"F/A RATIO DATA FOR CLOSED LOOP
 CONTROL IS OUT OF LIMITS!"
6690      GOSUB Cooldown
6700      GOSUB Print_data
6710      GOTO Restart
6720    ELSE
6730      J=24
6740      GOSUB Control_loop
6750    END IF
6760    Setpoint=Fuel_sp
6770    J=26
6780    GOSUB Confirm_sp
6790    Fuel_sp=Setpoint
6800    PRINTER IS 1
6810 Air:  !
6820    IF Control_ind(1)=0 THEN GOTO Back
6830    IF Dval(15)=0. OR Dval(15)=99.99 THEN
6840      PRINTER IS 701
6850      PRINT USING "8A,2X,55A";TIME$(TIMEDATE),"AIR FLOW DATA FOR CLOSED LOOP
CONTROL IS OUT OF LIMITS!"
6860      GOSUB Print_data
6870      GOSUB Cooldown
6880      GOTO Restart
6890    ELSE
6900      J=15
6910      GOSUB Control_loop
6920    END IF
6930    Setpoint=Air_sp
6940    J=27
6950    GOSUB Confirm_sp
6960    Air_sp=Setpoint
6970    PRINTER IS 1
6980 Back:  !
6990    IF Control_ind(3)=0 THEN GOTO 7150
7000    IF Dval(23)=0. OR Dval(23)=9999. THEN
7010      PRINTER IS 701
7020      PRINT USING "8A,2X,55A";"SYS. PSI DATA FOR CLOSED LOOP CONTROL IS OUT O
F LIMITS!"
7030      GOSUB Cooldown
7040      GOSUB Print_data
7050      GOTO Restart
7060    ELSE
7070      J=23
7080      GOSUB Control_loop
7090    END IF
```

```
7100   Setpoint=Back_sp
7110   J=29
7120   GOSUB Confirm_sp
7130   Back_sp=Setpoint
7140   PRINTER IS 1
7150   GOSUB Update_valves
7160   RETURN
7170 Control_loop:  !
7180   SELECT J
7190   CASE 24                       ! F/A RATIO
7200     Err=Dval(30)-Dval(24)
7210     Pid=1
7220     Sp_fraction=Fuel_sp/100
7230     GOSUB Pid
7240     Fuel_sp=Out*100
7250   CASE 15                       ! AIR MASS FLOW
7260     Err=Dval(31)-Dval(15)
7270     Pid=2
7280     Sp_fraction=Air_sp/100
7290     GOSUB Pid
7300     Air_sp=Out*100
7310   CASE 23                       ! SYS. PSI - REVERSED CONTROL
7320     Err=Dval(32)-Dval(23)
7330     Pid=3
7340     Sp_fraction=Back_sp/100
7350     GOSUB Pid
7360     Out=Sp_fraction+(Sp_fraction-Out)
7370     Back_sp=Out*100
7380   END SELECT
7390   RETURN
7400 Pid:  !
7410   IF Err<=-P(3,Pid) THEN
7420     Prop=(Err+P(3,Pid))*P(4,Pid)-P(3,Pid)*P(2,Pid)
7430   ELSE
7440     IF Err<P(3,Pid) THEN
7450       Prop=Err*P(2,Pid)
7460     ELSE
7470       Prop=(Err-P(3,Pid))*P(5,Pid)+P(3,Pid)*P(2,Pid)
7480     END IF
7490   END IF
7500   Amt(Pid)=Sp_fraction+Prop*(Tloop)*P(7,Pid)
7510   IF Amt(Pid)>P(1,Pid) THEN Amt(Pid)=P(1,Pid)
7520   IF Amt(Pid)<-P(1,Pid) THEN Amt(Pid)=-P(1,Pid)
7530   Out=Prop+Amt(Pid)+((Prop-P_prop(Pid))/(Tloop))*P(6,Pid)
7540   IF Out>1 THEN Out=1.
7550   P_prop(Pid)=Prop
7560   RETURN
7570 Pid_parm:    !
7580   CLEAR SCREEN
7590   PRINT
7600   PRINT
7610   PRINT "CURRENT CLOSED LOOP PARAMETERS"
7620   PRINT
7630   PRINT "1. F/A RATIO"
7640   PRINT "2. MASS AIR FLOW"
7650   PRINT "3. SYSTEM PRESSURE"
7660   PRINT "4. COMBUSTOR TEMP"
7670   PRINT "5. QUENCH TEMP"
7680   INPUT "ENTER INDEX OF PARAMETER (0 TO QUIT)",Index
7690   IF Index=0 THEN GOTO Restart
```

```
7700   GOSUB Pid_val_input
7710   GOTO Restart
7720 Pid_val_input:  !
7730   CLEAR SCREEN
7740   IF Index=1 THEN PRINT "FUEL / AIR RATIO"
7750   IF Index=2 THEN PRINT "MASS AIR FLOW"
7760   IF Index=3 THEN PRINT "SYSTEM PRESSURE"
7770   IF Index=4 THEN PRINT "COMB TEMPERATURE"
7780   IF Index=5 THEN PRINT "QUENCH TEMPERATURE"
7790   PRINT "CONTROL LOOP PARAMETERS"
7800   PRINT
7810   PRINT "1) RESET LIMIT=";P(1,Index)
7820   PRINT "2) MID-BAND GAIN=";P(2,Index)
7830   PRINT "3) 1/2 MID-BAND WIDTH=";P(3,Index)
7840   PRINT "4) LOW BAND GAIN=";P(4,Index)
7850   PRINT "5) HI BAND GAIN=";P(5,Index)
7860   PRINT "6) RATE CONSTANT=";P(6,Index)
7870   PRINT "7) RESET CONSTANT=";P(7,Index)
7880   PRINT
7890   INPUT "ENTER # TO EDIT, 0 TO QUIT, OR -1 TO RECALL LAST STORED SET",J
7900   SELECT J
7910   CASE -1
7920     GOSUB Read_pid_val
7930     GOTO Pid_val_input
7940   CASE 0
7950     GOSUB Write_pid_val
7960   CASE ELSE
7970     INPUT "ENTER NEW VALUE",P(J,Index)
7980     GOTO Pid_val_input
7990   END SELECT
8000   RETURN
8010 Print_header_1:  !
8020   PRINTER IS 701
8030   PRINT CHR$(12)
8040   PRINT DATE$(TIMEDATE),"           PRINTOUT OF TEST DATA"
8050   PRINT
8060   PRINT
8070   PRINT "* THESE ARE THE PARAMETERS TO BE PRINTED OUT"
8080   FOR I=1 TO 11
8090     PRINT USING 8100;I,".",Sensor$(Print_order(I))," = ",Chan_label$(Print_
order(I))
8100     IMAGE 2D,A,2X,5A,3A,16A
8110   NEXT I
8120   PRINT
8130   PRINT USING "#,8X"
8140   FOR I=1 TO 11
8150     PRINT USING "#,XXX,DD,X";I
8160   NEXT I
8170   PRINT
8180   PRINT USING "#,10A";"  TIME    "
8190   FOR I=1 TO 11
8200     PRINT USING "#,5A,X";Sensor$(Print_order(I))
8210   NEXT I
8220   PRINT
8230   PRINT USING "#,10X"
8240   FOR I=1 TO 11
8250     PRINT USING "#,4A,2X";Unit$(Print_order(I))
8260   NEXT I
8270   PRINT
8280   PRINTER IS 1
```

```
8290   RETURN
8300 Man_prt_stor:   !
8310   GOSUB Print_data
8320   GOSUB Store_data
8330   RETURN
8340 Print_data:  !
8350   PRINTER IS 701
8360   GOSUB Check
8370   PRINT USING "8A,2X,#";TIME$(TIMEDATE)
8380   FOR I=1 TO 11
8390     PRINT USING Display_format$(Print_order(I))&",X,#";Dval(Print_order(I))
8400   NEXT I
8410   PRINT
8420   PRINTER IS 1
8430   RETURN
8440 Store_data:   !                      !!!   Store data temporarily in buffer
8450   IF Data_pts=500 THEN
8460     GOSUB Write_data
8470   END IF
8480   Data_pts=Data_pts+1
8490   Stor_buf(1,Data_pts)=Data_pts
8500   Stor_buf(2,Data_pts)=Trun/3600
8510   FOR I=1 TO 11
8520     Stor_buf(2+I,Data_pts)=Dval(Print_order(I))
8530   NEXT I
8540   RETURN
8550 Cooldown:    !
8560   Flag(6)=0
8570   MAT Control_ind= (0.)
8580   MAT Flag= (0.)
8590   Flag(1)=2
8600   Prt_int=-1
8610   Fa_ratio_sp=-.999
8620   Fuel_sp=0.
8630   ON KEY 6 LABEL "RESTART ",10 GOTO Rig_restart
8640   Sys_psi_sp=-999.
8650   Back_sp=80.
8660   ON KEY 7 LABEL " % BACK  VALVE",10 GOTO Back_out_sp
8670   Air_flow_sp=-9.99
8680   Air_sp=60.
8690   ON KEY 5 LABEL " % AIR   VALVE",10 GOTO Air_out_sp
8700   Quench_sp=0.
8710   GOSUB Update_valves
8720   ON KEY 1 LABEL "  STOP    SCAN",10 GOTO Pgm_stop
8730   PRINT USING 8800;"SHUTDOWN SEQUENCE IS BEING INITIATED."
8740   PRINT USING 8790;"NEW AIR  VALVE SETPOINT IS ",Air_sp,"%."
8750   PRINT USING 8790;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%."
8760   PRINT USING 8790;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%."
8770   PRINT USING 8790;"NEW H2O  VALVE SETPOINT IS ",Quench_sp,"%."
8780   PRINT USING 8800;"AUTO PRINT/STORE INTERVAL TURNED OFF."
8790   IMAGE 10X,27A,3D.D,2A
8800   IMAGE 10X,37A
8810   PRINTER IS 1
8820   RETURN
8830 Ignite_sp:  !
8840   Fuel_sp=Ignite_sp(1)
8850   ON KEY 6 LABEL " % FUEL  VALVE",10 GOTO Fuel_out_sp
8860   Air_sp=Ignite_sp(2)
8870   Back_sp=Ignite_sp(3)
8880   Quench_sp=Ignite_sp(4)
```

```
8890   GOSUB Update_valves
8900   PRINTER IS 701
8910   PRINT USING 8920;TIME$(TIMEDATE),"PREVIOUS LIGHT OFF CONDITIONS HAVE BEEN
 RECALLED."
8920   IMAGE 8A,2X,49A
8930   PRINT USING 8970;"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%."
8940   PRINT USING 8970;"NEW AIR  VALVE SETPOINT IS ",Air_sp,"%."
8950   PRINT USING 8970;"NEW BACK VALVE SETPOINT IS ",Back_sp,"%."
8960   PRINT USING 8970;"NEW H2O  VALVE SETPOINT IS ",Quench_sp,"%."
8970   IMAGE 10X,27A,3D.D,2A
8980   PRINTER IS 1
8990   RETURN
9000 Light_off:  !
9010   Flag(1)=1
9020   Tstart(1)=TIMEDATE
9030   IF Dval(24)<.070 THEN Flag(5)=0
9040   IF Dval(24)>.070 THEN Flag(5)=1
9050   Ignite_sp(1)=Fuel_sp
9060   Ignite_sp(2)=Air_sp
9070   Ignite_sp(3)=Back_sp
9080   Ignite_sp(4)=Quench_sp
9090   Quench_sp=60.
9100   GOSUB Update_valves
9110   Life_cycles=Life_cycles+1
9120   FOR I=1 TO 2
9130     IF Specimen$(I)="EMPTY" THEN GOTO 9150
9140     Cycles(I)=Cycles(I)+1
9150   NEXT I
9160   PRINTER IS 701
9170   PRINT USING "8A,2X,43A";TIME$(TIMEDATE),"RIG HAS BEEN IGNITED!"
9180   PRINT USING 9190;"NEW H2O  VALVE SETPOINT IS ",Quench_sp,"%."
9190   IMAGE 10X,27A,3D.D,2A
9200   PRINTER IS 1
9210   RETURN
9220 Quench_out_sp:  !
9230   PRINT TABXY(1,27);"PRESENT %OUTPUT OF H2O VALVE IS ";DROUND(Quench_sp,4);
"%."
9240   INPUT "ENTER NEW %OUTPUT OF H2O VALVE",Quench_sp
9250   Setpoint=Quench_sp
9260   J=28
9270   GOSUB Confirm_sp
9280   Quench_sp=Setpoint
9290   Quench_control$="OPEN"
9300   GOSUB Update_valves
9310   PRINT USING 9320;TIME$(TIMEDATE),"NEW H2O VALVE SETPOINT IS ",Quench_sp,"
%."
9320   IMAGE 8A,2X,26A,3D.D,2A
9330   PRINTER IS 1
9340   GOTO Restart
9350 Air_out_sp:   !
9360   PRINT TABXY(1,27);"PRESENT %OUTPUT OF AIR VALVE IS ";DROUND(Air_sp,4);"%.
"
9370   INPUT "ENTER NEW %OUTPUT OF AIR VALVE",Air_sp
9380   Setpoint=Air_sp
9390   J=27
9400   GOSUB Confirm_sp
9410   Air_sp=Setpoint
9420   Control_ind(1)=0
9430   Air_flow_sp=-9.99
9440   GOSUB Update_valves
```

```
9450   PRINT USING 9460;TIME$(TIMEDATE),"NEW AIR VALVE SETPOINT IS ",Air_sp,"%."
9460   IMAGE 8A,2X,26A,3D.D,2A
9470   PRINTER IS 1
9480   GOTO Restart
9490 Air_flow_sp:  !
9500   PRINT TABXY(1,27);"PRESENT AIR FLOW SETPOINT IS ";Air_flow_sp;" LBM/SEC."
9510   INPUT "ENTER NEW AIR FLOW SETPOINT VALUE",Air_flow_sp
9520   Setpoint=Air_flow_sp
9530   J=31
9540   GOSUB Confirm_sp
9550   Air_flow_sp=Setpoint
9560   Control_ind(1)=1
9570   PRINT USING 9580;TIME$(TIMEDATE),"NEW AIR FLOW SETPOINT IS ",Air_flow_sp,
" LBM/HR."
9580   IMAGE 8A,2X,25A,2D.2D,8A
9590   PRINTER IS 1
9600   GOTO Restart
9610 Back_out_sp:  !
9620   PRINT TABXY(1,27);"PRESENT %OUTPUT OF BACK PSI VALVE IS ";DROUND(Back_sp,
4);"%."
9630   INPUT "ENTER NEW %OUTPUT OF BACK PSI VALVE",Back_sp
9640   Setpoint=Back_sp
9650   J=29
9660   GOSUB Confirm_sp
9670   Back_sp=Setpoint
9680   Control_ind(3)=0
9690   Sys_psi_sp=-999.
9700   GOSUB Update_valves
9710   PRINT USING 9720;TIME$(TIMEDATE),"NEW BACK PSI VALVE SETPOINT IS ",Back_s
p,"%."
9720   IMAGE 8A,2X,31A,3D.D,2A
9730   PRINTER IS 1
9740   GOTO Restart
9750 Sys_psi_sp:  !
9760   PRINT TABXY(1,27);"PRESENT SYS. PSI SETPOINT IS ";Sys_psi_sp;" ."
9770   INPUT "ENTER NEW SYS. PSI SETPOINT VALUE",Sys_psi_sp
9780   Setpoint=Sys_psi_sp
9790   J=32
9800   GOSUB Confirm_sp
9810   Sys_psi_sp=Setpoint
9820   Control_ind(3)=1
9830   PRINT USING 9840;TIME$(TIMEDATE),"NEW SYS. PSI SETPOINT IS ",Sys_psi_sp,"
 ."
9840   IMAGE 8A,2X,25A,DDD.D,2A
9850   PRINTER IS 1
9860   GOTO Restart
9870 Fuel_out_sp:  !
9880   PRINT TABXY(1,27);"PRESENT %OUTPUT OF FUEL VALVE IS ";DROUND(Fuel_sp,4);"
%."
9890   INPUT "ENTER NEW %OUTPUT OF FUEL VALVE",Fuel_sp
9900   Setpoint=Fuel_sp
9910   J=26
9920   GOSUB Confirm_sp
9930   Fuel_sp=Setpoint
9940   Control_ind(2)=0
9950   Fa_ratio_sp=-.999
9960   GOSUB Update_valves
9970   PRINT USING 9980;TIME$(TIMEDATE),"NEW FUEL VALVE SETPOINT IS ",Fuel_sp,"%
."
9980   IMAGE 8A,2X,27A,3D.D,2A
```

```
9990   PRINTER IS 1
10000  GOTO Restart
10010 Fa_ratio_sp: !
10020  PRINT TABXY(1,27);"PRESENT F/A RATIO SETPOINT IS ";Fa_ratio_sp;" ."
10030  INPUT "ENTER NEW F/A RATIO SETPOINT VALUE",Fa_ratio_sp
10040  Setpoint=Fa_ratio_sp
10050  J=27
10060  GOSUB Confirm_sp
10070  Fa_ratio_sp=Setpoint
10080  Control_ind(2)=1
10090  PRINT USING 10100;TIME$(TIMEDATE),"NEW F/A RATIO SETPOINT IS ",Fa_ratio_s
p,"."
10100  IMAGE 8A,2X,26A,.DDD,A
10110  PRINTER IS 1
10120  GOTO Restart
10130 Update_valves:  !
10140  Airout=INT((100-Air_sp)*100)
10150  OUTPUT 709;"AO2,1,"&VAL$(Airout)
10160  Fuelout=INT(Fuel_sp*100)
10170  OUTPUT 709;"AO3,1,"&VAL$(Fuelout)
10180  Backout=INT(Back_sp*100)
10190  OUTPUT 709;"AO2,0,"&VAL$(Backout)
10200  Quenchout=INT(Quench_sp*100)
10210  OUTPUT 709;"AO4,0,"&VAL$(Quenchout)
10220  RETURN
10230 Confirm_sp:  !
10240  IF Setpoint>Hi_lim(J) THEN Setpoint=Hi_lim(J)
10250  IF Setpoint<Low_lim(J) THEN Setpoint=Low_lim(J)
10260  PRINT TABXY(1,27);Blank$
10270  PRINTER IS 701
10280  RETURN
10290 Read_pid_val: !
10300  ASSIGN @Pid TO "X6PID_5"
10310  ENTER @Pid;P(*)
10320  ASSIGN @Pid TO *
10330  RETURN
10340 Write_pid_val: !
10350  ASSIGN @Pid TO "X6PID_5"
10360  OUTPUT @Pid;P(*)
10370  ASSIGN @Pid TO *
10380  RETURN
10390 Read_common: !
10400  ASSIGN @Path_1 TO "X6_LOG"
10410  ENTER @Path_1;Tcomb,Life_cycles
10420  ENTER @Path_1;Test$,Parm$(*)
10430  ENTER @Path_1;Specimen$(*),Install$(*),Cycles(*),Tlean(*),Trich(*)
10440  ENTER @Path_1;Ignite_sp(*),Spec_info$(*)
10450  ASSIGN @Path_1 TO *
10460  RETURN
10470 Write_common: !
10480  ASSIGN @Path_1 TO "\BLP\PGMS\X6_LOG:DOS,C"
10490  OUTPUT @Path_1;Tcomb,Life_cycles
10500  OUTPUT @Path_1;Test$,Parm$(*)
10510  OUTPUT @Path_1;Specimen$(*),Install$(*),Cycles(*),Tlean(*),Trich(*)
10520  OUTPUT @Path_1;Ignite_sp(*),Spec_info$(*)
10530  ASSIGN @Path_1 TO *
10540  RETURN
10550 Write_data: !
10560  MASS STORAGE IS "\BLP\X6_BDATS:DOS,C"
10570  Ans$=DATE$(TIMEDATE)
```

```
10580  Bytes=16+30*11+(11+2)*Data_pts*8
10590  Bytes=INT(Bytes/256+1)
10600  File_name$=Ans$[10,11]&Ans$[4,6]&Ans$[1,2]&Suffix$(J)[1,1]
10610  ON ERROR GOTO Off_error
10620  CREATE BDAT File_name$,Bytes
10630  ASSIGN @Path_1 TO File_name$
10640  OUTPUT @Path_1;File_name$,Data_pts
10650  FOR I=1 TO 11
10660    OUTPUT @Path_1;Chan_label$(Print_order(I))
10670    OUTPUT @Path_1;Display_format$(Print_order(I))
10680  NEXT I
10690  MAT Array= Stor_buf(1:13,1:Data_pts)
10700  OUTPUT @Path_1;Array(*)
10710  ASSIGN @Path_1 TO *
10720  MASS STORAGE IS "\BLP\PGMS:DOS,C"
10730  MAT Stor_buf= (0.)
10740  RETURN
10750 Off_error:  !
10760  OFF ERROR
10770  IF ERRN=54 THEN
10780    J=J+1
10790    GOTO 10600
10800  ELSE
10810    DISP ERRM$
10820    PAUSE
10830  END IF
10840 Set_display: !
10850  IF Flag(6)=0 THEN
10860    Flag(6)=1
10870    Flag(2)=0
10880    ON KEY 3 LABEL "TABULAR DISPLAY",10 GOTO Set_display
10890  ELSE
10900    Flag(6)=0
10910    Flag(3)=0
10920    ON KEY 3 LABEL "GRAPHIC DISPLAY",10 GOTO Set_display
10930  END IF
10940  GOTO Restart
10950 Set_prt_int: !
10960  INPUT "ENTER NEW INTERVAL IN SECONDS (-1=OFF)",Prt_int
10970  Tstart(3)=TIMEDATE
10980  PRINTER IS 701
10990  IF Prt_int=-1 THEN
11000    PRINT USING 11010;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL HAS BEEN T
URNED OFF!"
11010    IMAGE 8A,2X,46A
11020  ELSE
11030    PRINT USING 11040;TIME$(TIMEDATE),"AUTO PRINT/STORE INTERVAL SET AT ",P
rt_int/60.," MINUTES."
11040    IMAGE 8A,2X,33A,2D.D,9A
11050    GOSUB Man_prt_stor
11060  END IF
11070  PRINTER IS 1
11080  GOTO Restart
11090 Insert:  !
11100  Flag(4)=1
11110  Tstart(2)=TIMEDATE
11120  PRINTER IS 701
11130  PRINT USING 11140;TIME$(TIMEDATE),"SPECIMEN HAS BEEN INSERTED !"
11140  IMAGE 8A,2X,28A
11150  PRINTER IS 1
```

```
11160  RETURN
11170 Retract:  !
11180  Flag(4)=0
11190  Tretract=Tinsert
11200  PRINTER IS 701
11210  PRINT USING 11140;TIME$(TIMEDATE),"SPECIMEN HAS BEEN RETRACTED!"
11220  PRINTER IS 1
11230  RETURN
11240 Statistics:  !
11250  FOR J=3 TO 11
11260    Stat(2,J-2)=Array(J,1)
11270    Stat(3,J-2)=Array(J,1)
11280    FOR I=1 TO Data_pts
11290      Stat(1,J-2)=Stat(1,J-2)+Array(J,I)
11300      IF Array(J,I)<Stat(2,J-2) THEN Stat(2,J-2)=Array(J,I)
11310      IF Array(J,I)>Stat(3,J-2) THEN Stat(3,J-2)=Array(J,I)
11320    NEXT I
11330    Stat(1,J-2)=Stat(1,J-2)/Data_pts
11340    FOR I=1 TO Data_pts
11350      Stat(4,J-2)=Stat(4,J-2)+(Array(J,I)-Stat(1,J-2))^2
11360    NEXT I
11370    Stat(4,J-2)=(Stat(4,J-2)/(Data_pts-1))^.5
11380  NEXT J
11390  RETURN
11400 Summary:  !
11410  PRINTER IS 26
11420  PRINT USING "13A,11A";"RUN SUMMARY: ",DATE$(TIMEDATE)
11430  PRINT
11440  PRINT "                    .................FACILITY NOTES................."
11450  PRINT
11460  PRINT USING "25A,DDD.D";"TOTAL # COMBUSTOR HOURS: ",Tcomb
11470  PRINT USING "25A,DDD.D";"TOTAL # COMBUSTOR CYCS.: ",Life_cycles
11480  PRINT
11490  PRINT USING "19A,DD.D";"TODAY'S RUN (HRS): ",Trun/3600
11500  PRINT USING "19A,DD.D";"INSERT TIME (HRS): ",Tinsert/3600
11510  PRINT USING "19A,DDD.";"FUEL BURNED (GAL): ",Fuel_lbs/6.74
11520  PRINT USING "19A,8A";"STORAGE  FILENAME: ",File_name$
11530  PRINT USING "19A,DDD.";"       # DATA PTS: ",Data_pts
11540  PRINT
11550  PRINT "                    ................TEST  STATISTICS................"
11560  PRINT
11570  PRINT USING 11580;"PARAMETER","TARGET","AVERAGE","MINIMUM","MAXIMUM","STD
.DEV."
11580  IMAGE 9A,5X,6A,10X,7A,7X,7A,7X,7A,6X,8A
11590  PRINT
11600  RESTORE 11650
11610  FOR I=1 TO 9
11620    READ Ans$,Image$
11630    PRINT USING Image$;Ans$,Parm$(I),Stat(1,I),Stat(2,I),Stat(3,I),Stat(4,I
)
11640  NEXT I
11650  DATA "AIR FLOW","8A,6X,10A,7X,DD.DD,9X,DD.DD,9X,DD.DD,9X,DD.DD"
11660  DATA "FA RATIO","8A,6X,10A,7X,.DDDD,9X,.DDDD,9X,.DDDD,9X,.DDDD"
11670  DATA "PRESSURE","8A,6X,10A,7X,DDD.D,9X,DDD.D,9X,DDD.D,9X,DDD.D"
11680  DATA "VELOCITY","8A,6X,10A,7X,DDD.D,9X,DDD.D,9X,DDD.D,9X,DDD.D"
11690  DATA "GAS TEMP","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11700  DATA "SRF TEMP","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11710  DATA "TC AC021","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11720  DATA "TC AC024","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
11730  DATA "TC AC026","8A,6X,10A,7X,DDDD.,9X,DDDD.,9X,DDDD.,9X,DDDD."
```

```
11740  PRINT
11750  GOSUB Spec_info
11760  PRINT
11770  PRINT "                   ...................COMMENTS..................."
11780  PRINT CHR$(12)
11790  PRINTER IS 1
11800  RETURN
11810 Control_setup:  !
11820  CLEAR SCREEN
11830  Flag(2)=0
11840  Flag(3)=0
11850  PRINT
11860  PRINT "      RIG CONTROL OPTIONS"
11870  PRINT
11880  PRINT "1) FUEL VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11890  PRINT "2) FUEL VALVE: CLOSED LOOP CONTROL OF F/A RATIO"
11900  PRINT "3) AIR  VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11910  PRINT "4) AIR  VALVE: CLOSED LOOP CONTROL OF AIR FLOW"
11920  PRINT "5) H2O  VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11930  PRINT "6) BACK VALVE: MANUAL CONTROL OF % OPEN/CLOSE"
11940  PRINT "7) BACK VALVE: CLOSED LOOP CONTROL OF SYS. PSI"
11950  PRINT
11960  PRINT
11970  PRINT "      OTHER SETUP OPTIONS"
11980  PRINT
11990  PRINT "8) EDIT/REVIEW PID PARAMETERS       "
12000  PRINT
12010  PRINT
12020  INPUT "ENTER YOUR CHOICE OR (0) TO RETURN",Index
12030  SELECT Index
12040  CASE 0
12050    GOTO Restart
12060  CASE 1
12070    ON KEY 6 LABEL " % FUEL  VALVE",10 GOTO Fuel_out_sp
12080    GOTO Fuel_out_sp
12090  CASE 2
12100    ON KEY 6 LABEL "  F/A    RATIO",10 GOTO Fa_ratio_sp
12110    GOTO Fa_ratio_sp
12120  CASE 3
12130    ON KEY 5 LABEL " %  AIR  VALVE",10 GOTO Air_out_sp
12140    GOTO Air_out_sp
12150  CASE 4
12160    ON KEY 5 LABEL "  AIR     FLOW",10 GOTO Air_flow_sp
12170    GOTO Air_flow_sp
12180  CASE 5
12190    ON KEY 8 LABEL " %  H2O  VALVE",10 GOTO Quench_out_sp
12200    GOTO Quench_out_sp
12210  CASE 6
12220    ON KEY 7 LABEL " % BACK  VALVE",10 GOTO Back_out_sp
12230    GOTO Back_out_sp
12240  CASE 7
12250    ON KEY 7 LABEL "SYS. PSI",10 GOTO Sys_psi_sp
12260    GOTO Sys_psi_sp
12270  CASE 8
12280    GOTO Pid_parm
12290  CASE ELSE
12300    GOTO Control_setup
12310  END SELECT
12320 Build_string: !
12330  L1$=" "
```

```
12340  L4$="    "
12350  FOR I=1 TO 15
12360    N=Screen(I,1)
12370    IF N=40 THEN
12380      Part1_disp$="                                "
12390    ELSE
12400      OUTPUT L5$ USING Display_format$(N)&",#";Dval(N)
12410      L6$="......"
12420      Part1_disp$=Chan_label$(N)[1,16]&L6$[1,6]&L5$[1,5]&L1$[1,1]&Unit$(N)[
1,4]
12430    END IF
12440    N=Screen(I,2)
12450    IF N=40 THEN
12460      Part2_disp$="                                "
12470    ELSE
12480      OUTPUT L5$ USING Display_format$(N)&",#";Dval(N)
12490      L6$="......"
12500      Part2_disp$=Chan_label$(N)[1,16]&L6$[1,6]&L5$[1,5]&L1$[1,1]&Unit$(N)[
1,4]
12510    END IF
12520    Disp$(I)=Part1_disp$[1,32]&L4$[1,4]&Part2_disp$[1,32]
12530  NEXT I
12540  RETURN
12550 Modify_string: !
12560  FOR I=1 TO 15
12570    N=Screen(I,1)
12580    IF N=40 THEN
12590      GOTO 12640
12600    ELSE
12610      OUTPUT L5$ USING Display_format$(N)&",#";Dval(N)
12620    END IF
12630    Disp$(I)[23,27]=L5$[1,5]
12640    N=Screen(I,2)
12650    IF N=40 THEN
12660      GOTO 12710
12670    ELSE
12680      OUTPUT L5$ USING Display_format$(N)&",#";Dval(N)
12690    END IF
12700    Disp$(I)[59,63]=L5$[1,5]
12710  NEXT I
12720  RETURN
12730 Read_coef: !
12740  RESTORE 12790
12750  FOR I=1 TO 13
12760    READ Kref(I)
12770  NEXT I
12780  ! TYPE K POLYNOMIAL CONVERSION AND REFERENCE COEFFICIENTS
12790  DATA -8.16774E-7,3.964E-4,1.6E-8
12800  DATA -5.1E-2,2.48503E4,-3.82662E5,9.9661057E7,-1.0820624E10,6.0392855E11
12810  DATA -1.9109E13,3.4782347E14,-3.3991028E15,1.3828514E16
12820  FOR I=1 TO 13
12830    READ Rref(I)
12840  NEXT I
12850  ! TYPE R POLYNOMIAL CONVERSION AND REFERENCE COEFFICIENTS
12860  DATA -2.11284E-7,5.334E-5,1.2E-8
12870  DATA 4.8343651E1,1.109827E-1,-2.435389E-6,4.5164488E-11,1.8172612E-16,0,0
,0,0,0
12880  RETURN
12890 Read_suffix:  !
12900  RESTORE 12940
```

```
12910  FOR I=1 TO 10
12920    READ Suffix$(I)
12930  NEXT I
12940  DATA "A","B","C","D","E","F","G","H","I","J"
12950  RETURN
12960 Read_label_lim: !
12970  RESTORE 13050
12980  FOR I=1 TO 34
12990    READ Chan_label$(I),Sensor$(I),Display_format$(I),Unit$(I)
13000    READ Hi_lim(I),Low_lim(I)
13010  NEXT I
13020  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13030  !!!!   HP3497, SLOT# 0 - 20 CHANNEL MVX (A8-B9)         ! Dval(I),Volt(I)
13040  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13050  DATA "EXHAUST GAS TEMP","AC067","DDDD.","  F ",2500,0      ! 1
13060  DATA "VENTURI AIR TEMP","AC013","DDDD.","  F ",2500,0      ! 2
13070  DATA "INLET   AIR TEMP","AC024","DDDD.","  F ",2500,0      ! 3
13080  DATA "INLET   N2  TEMP","AC039","DDDD.","  F ",2500,0      ! 4
13090  DATA "PREHEAT AIR TEMP","AC012","DDDD.","  F ",2500,0      ! 5
13100  DATA "INSTR RING1 TEMP","AC021","DDDD.","  F ",3200,0      ! 6
13110  DATA "INSTR RING4 TEMP","AC024","DDDD.","  F ",3200,0      ! 7
13120  DATA "GAS STREAM  TEMP","AC046","DDDD.","  F ",3200,0      ! 8
13130  DATA "INSTR RING6 TEMP","AC026","DDDD.","  F ",3200,0      ! 9
13140  DATA "SPARE   -TYPE K-","KTC-7","DDDD.","  F ",2500,0      ! 10
13150  DATA "SPARE   -TYPE K-","KTC-8","DDDD.","  F ",2500,0      ! 11
13160  DATA "TC REF.  VOLTAGE"," REF ","DDDD.","MV  ",2500,0      ! 12
13170  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13180  !!!!   HP3497, SLOT# 1 - 20 CHANNEL MVX (A0-B0)
13190  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13200  DATA "INSERT   VOLTAGE","     ","DDDD.","    ",1000,0      ! 13
13210  DATA "SPECIMEN     TEMP","AC051","DDDD.","  F ",3200,1750  ! 14
13220  DATA "AIR          FLOW","AC008","DD.DD","#SEC",2.00,0     ! 15
13230  DATA "FUEL (Cox)   FLOW","FC227","DDDD.","#/HR",500.0,0    ! 16
13240  DATA "H2O-Quench   FLOW","WS075","DD.DD","GPM ",50.0,0     ! 17
13250  DATA "FUEL         FLOW","FC219","DDDD.","#/HR",500.,0     ! 18
13260  DATA "NITROGEN   PRESS","AC040","DDDD.","PSIG",1000,0      ! 19
13270  DATA "FUEL       PRESS","FC223","DDDD.","PSIG",1000,0      ! 20
13280  DATA "PREHEATED  PRESS","AC090","DDDD.","PSIG",1000,0      ! 21
13290  DATA "VIEWPORT   PRESS","AC050","DDDD.","PSIG",1000,0      ! 22
13300  DATA "TEST SECT  PRESS","AC091","DDDD.","PSIG",1000,0      ! 23
13310  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13320  !!!!   CALCULATED VALUES
13330  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
13340  DATA "FUEL/AIR   RATIO"," F/A ","D.DDD","    ",.150,0      ! 24
13350  DATA "GAS     VELOCITY","VGAS ","DDDD.","FT/S",3000,0      ! 25
13360  DATA "Fuel Valve %    ","FUEL ","DDD.D","%   ",100.,0      ! 26
13370  DATA "Air  Valve %    "," AIR ","DDD.D","%   ",100.,0      ! 27
13380  DATA "H2O  Valve %    ","WATER","DDD.D","%   ",100.,0      ! 28
13390  DATA "Back Valve %    ","BACK ","DDD.D","%   ",100.,0      ! 29
13400  DATA "F/A   Setpoint  ","FA_SP","D.DDD","    ",.150,0      ! 30
13410  DATA "Mair  Setpoint  ","AF_SP","DD.DD","#SEC",2.00,0      ! 31
13420  DATA "Ptest Setpoint  ","SP_SP","DDDD.","PSIG",1000,0      ! 32
13430  DATA "EQUIVALENT RATIO"," PHI ","DD.DD","    ",3.00,0      ! 33
13440  DATA "SPARE           ","     ","DDDD.","    ",1000,0      ! 34
13450  RETURN
13460 Screen_setup: !
13470  RESTORE 13550
13480  FOR I=1 TO 15
13490    READ Screen(I,1)
13500    READ Screen(I,2)
```

```
13510  NEXT I
13520  FOR I=1 TO 11
13530    READ Print_order(I)
13540  NEXT I
13550  DATA 4,19,3,20,5,22,7,21,8,23,14,40,1,15,40,18,24,16,33,17,25,40
13560  DATA 40,27,31,26,30,29,32,28,15,24,23,25,8,14,6,7,9,3,5
13570  RETURN
13580  !!!!!!!!!!!!!!!!!!!! UTILITY SUBROUTINES !!!!!!!!!!!!!!!!!!!!!!
13590 Restart: !
13600  IF Flag(1)=1 THEN Fuel_lbs=Fuel_lbs+Dval(16)*Tloop/3600
13610  OUTPUT 709;"VS1"
13620  OUTPUT 709;"VT3"
13630  GOTO Scan
13640 Rig_restart:  !
13650  GOSUB Log
13660  GOSUB Print_header_1
13670  GOTO Init_variables
13680 Invalid: !
13690  BEEP
13700  DISP "NOT VALID KEY"
13710  WAIT 1
13720  DISP "               "
13730  RETURN
13740 Shutdown:  !
13750  BEEP
13760  LINPUT "DO YOU REALLY WISH TO SHUTDOWN? (Y/N)",Ans$
13770  IF Ans$="Y" THEN
13780    PRINTER IS 701
13790    PRINT USING "8A,2X,38A";TIME$(TIMEDATE),"EMERGENCY SHUTDOWN HAS BEEN RE
QUESTED!"
13800    GOSUB Cooldown
13810    IF Flag(4)=1 THEN GOSUB Retract
13820    GOTO Restart
13830  ELSE
13840    GOTO Restart
13850  END IF
13860 Log:  !
13870  GOSUB Spec_update
13880  GOSUB Write_common
13890! IF Trun<60 THEN GOTO 13960
13900  IF Data_pts=0 THEN
13910    File_name$="No data!"
13920  ELSE
13930    J=1
13940    GOSUB Write_data
13950    GOSUB Statistics
13960  END IF
13970  GOSUB Summary
13980  RETURN
13990 Pgm_stop:  !
14000  GOSUB Log
14010  DISP "PROGRAM ENDS"
14020  BEEP 500,3
14030  WAIT 3
14040  CLEAR SCREEN
14050  GOTO Main_menu_keys
14060  STOP
14070  END
```

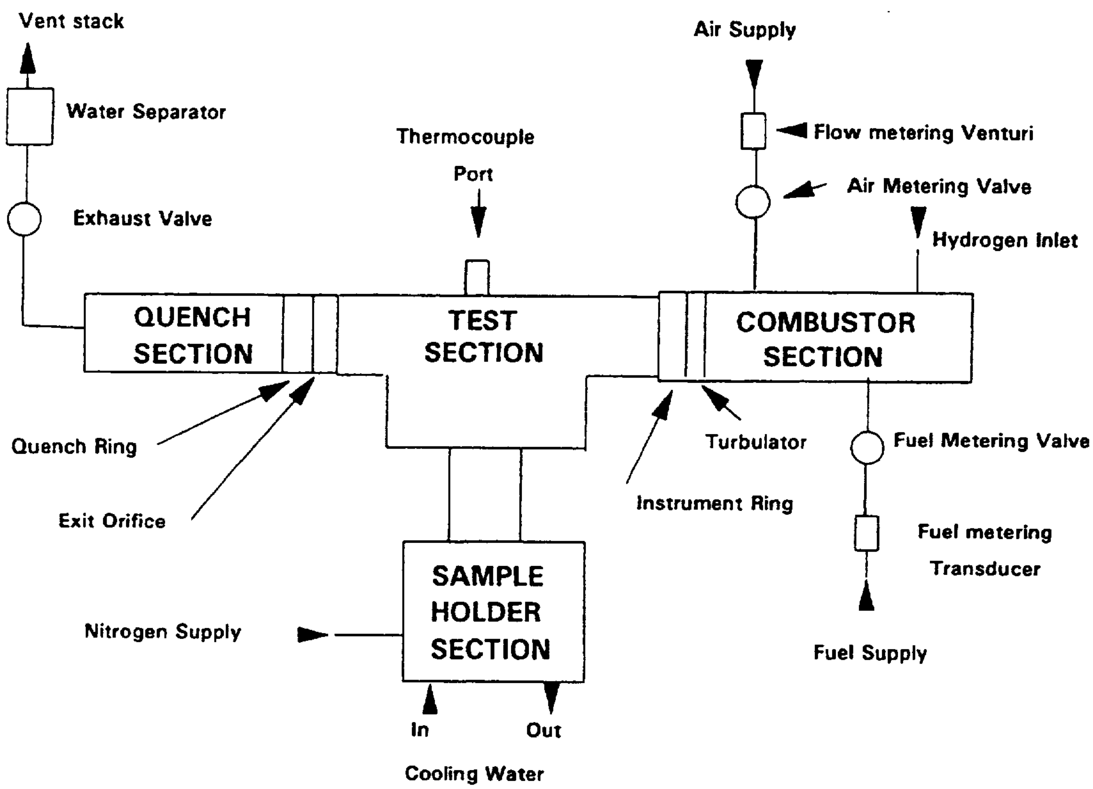

Figure 1.—Schematic of the burner rig configuration.

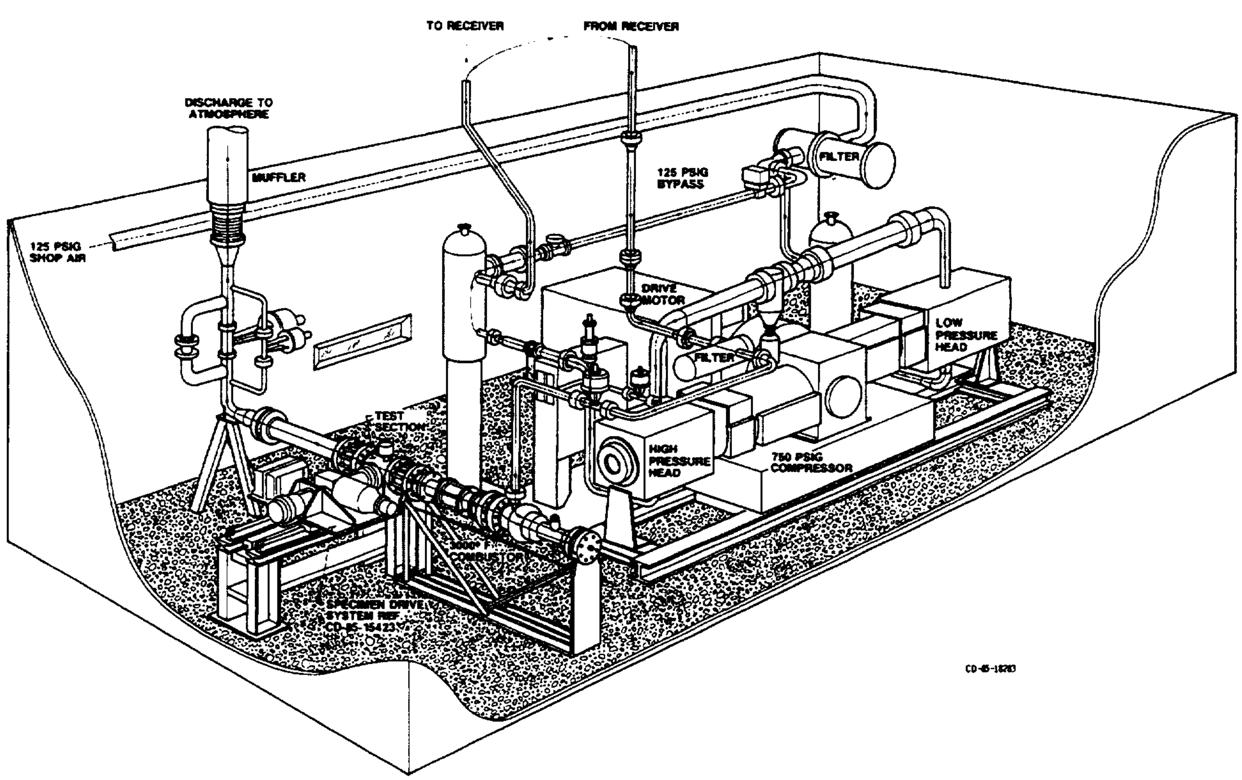

Figure 2.—Test cell layout including rig and supporting 400 horsepower, high-pressure compressor air supply.

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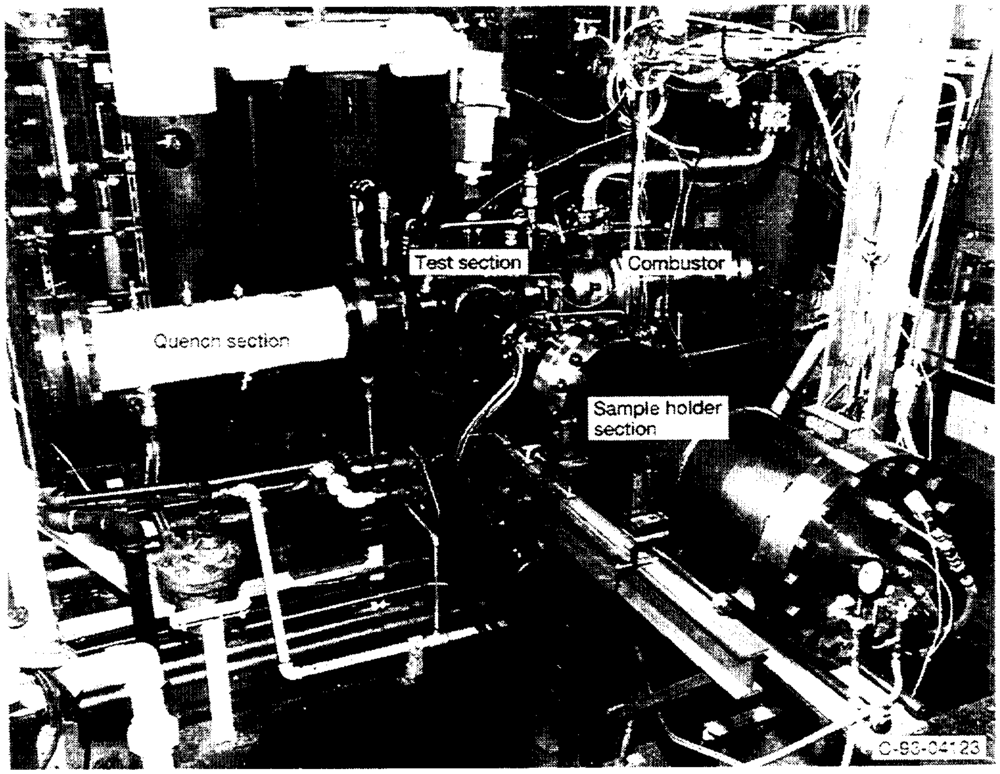


Figure 3.—Photograph of burner rig and test cell.

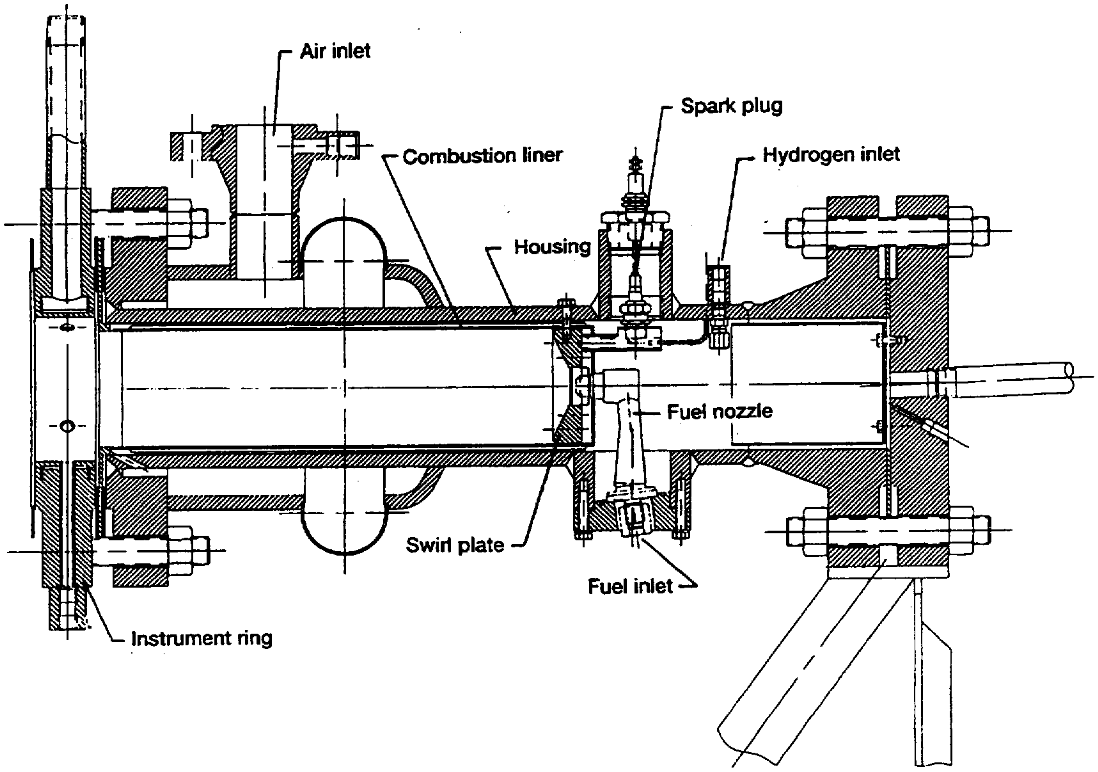
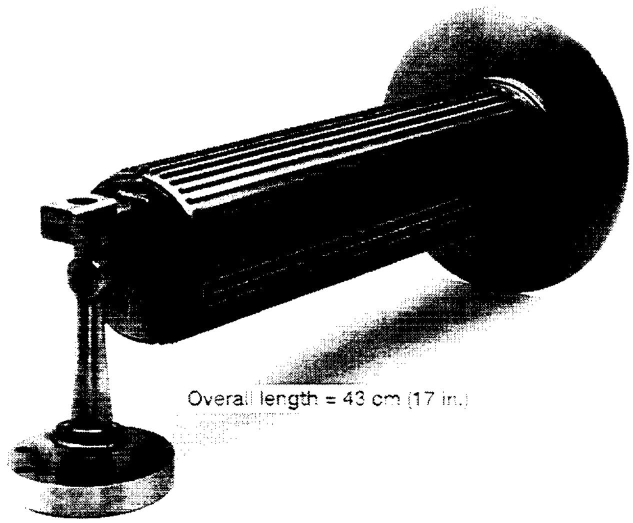


Figure 4.—Cross section of combustor.



C-93-04129

Figure 5.—Combustor liner, swirl plate, and fuel nozzle assembly.

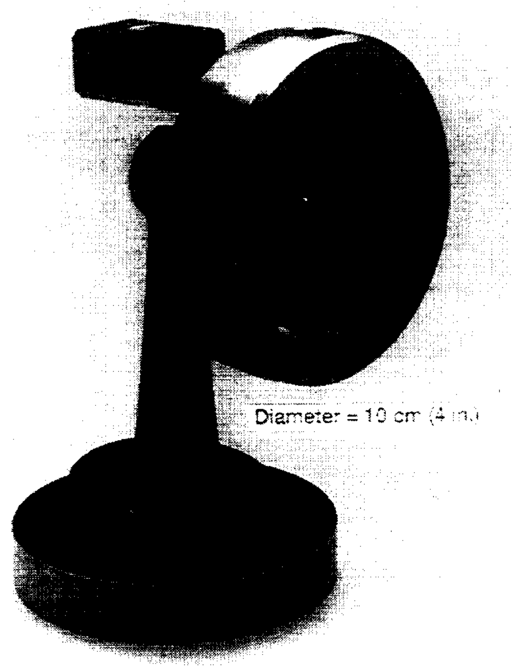


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Figure 6.—Swirl plate showing inlet air swirl angle and conical expansion dome configuration.

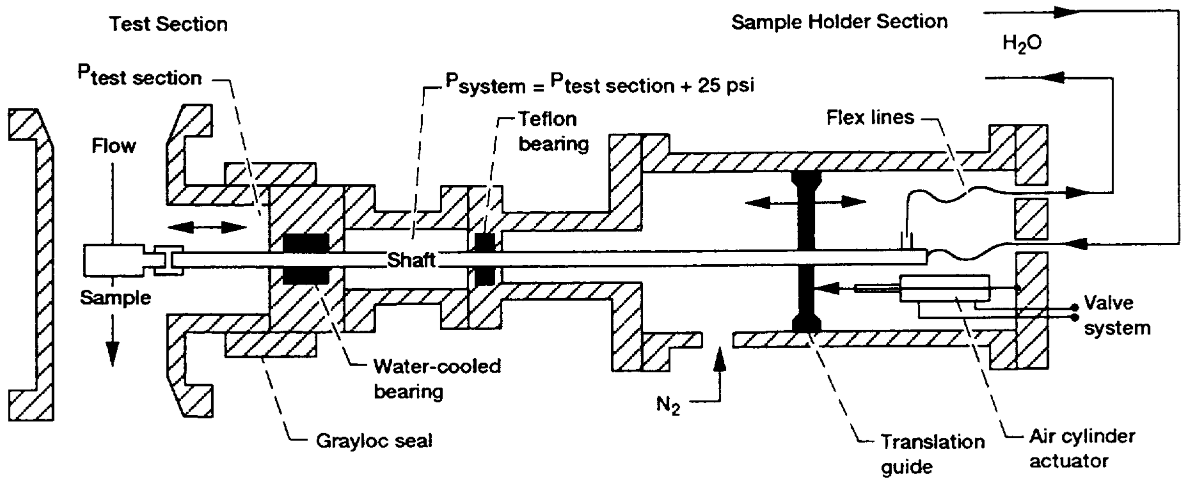

Figure 7.—Cross section of sample holder section.

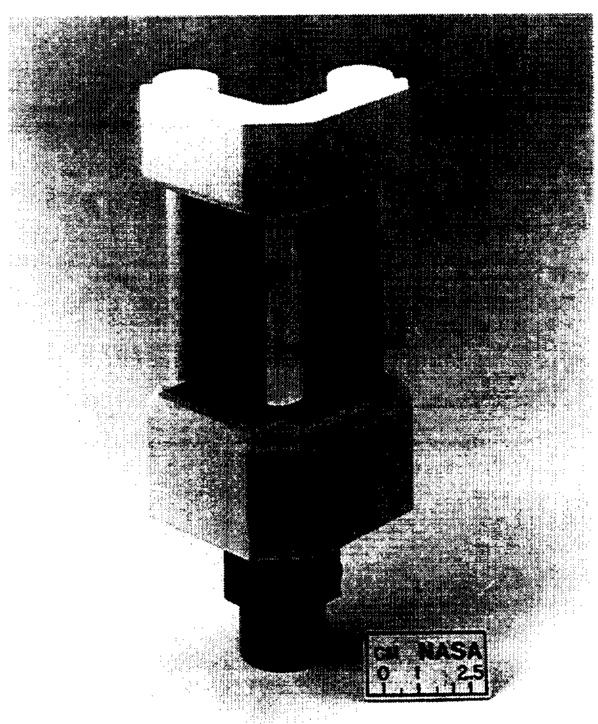

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Figure 8.—Thermal barrier coated sample holder assembled with blocks (lava & superalloy) and various size samples.

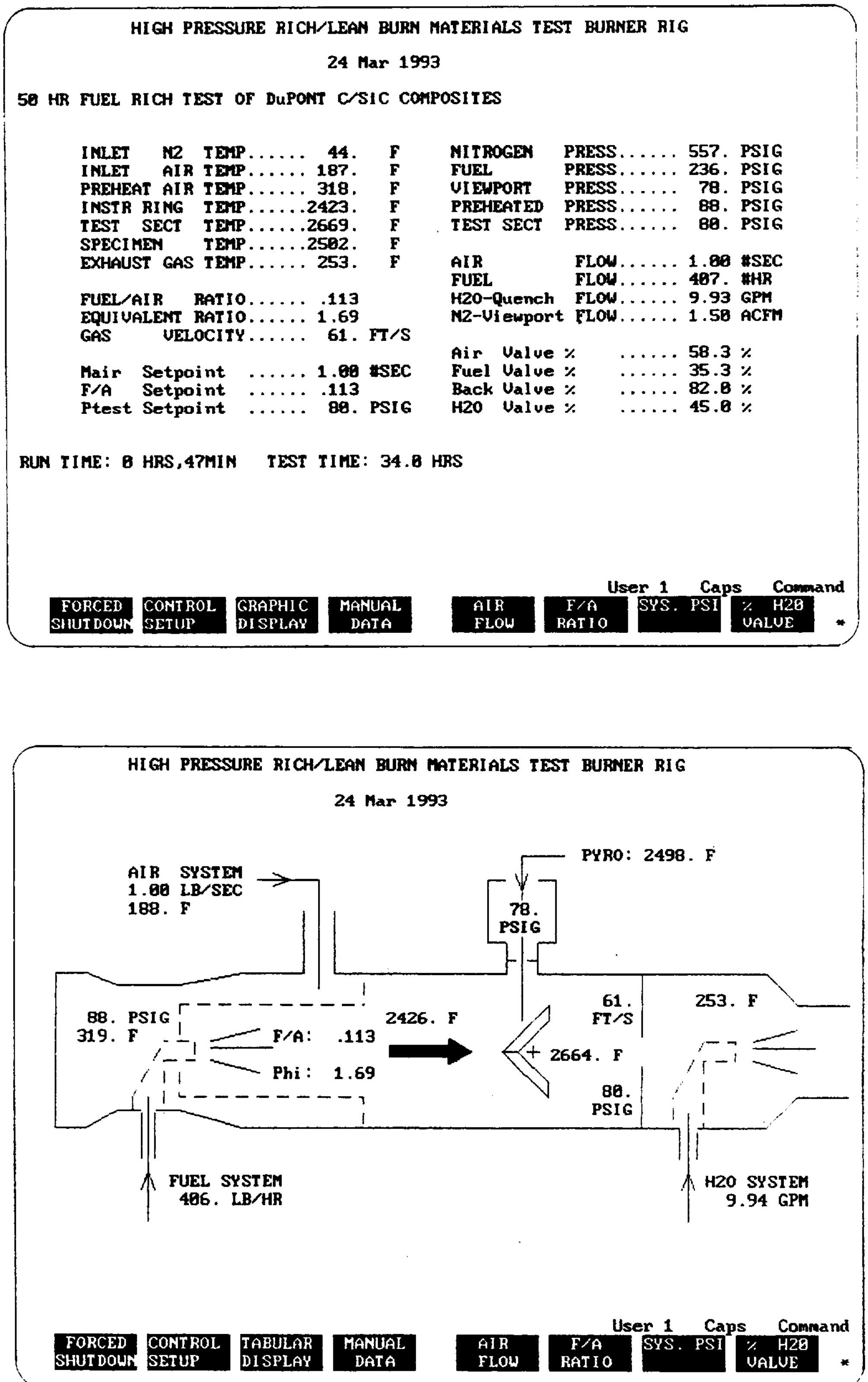

Figure 9.—Screen dumps of (a) tabular display and (b) graphics display including special function control keys.

RUN SUMMARY: 30 Apr 1993
B.F. GOODRICH SiC/SiC COMPOSITE - 50 HR RICH-BURN TEST

.................FACILITY NOTES.................

COMBUSTOR TIME LOGGED : 8 HRS,50MIN	TOTAL # COMBUSTOR HOURS :	176.5
INSERTED LEAN-BURN TIME : 0 HRS,0 MIN	TOTAL # COMBUSTOR CYCS. :	138
INSERTED RICH-BURN TIME : 8 HRS,43MIN		
GALLONS OF FUEL BURNED : 566.7		
FILENAME OF DATA FILE : 93APR30A		
NO. OF DATA PTS : 105		

................TEST PARAMETERS................

PARAMETER	TARGET	AVERAGE	STD.DEV.	MIN	MAX
AIR FLOW	1.0 LB/SEC	0.999	.0012	.9967	1.0044
FA RATIO	0.121	0.121	.0003	.1201	.1215
PRESSURE	80 PSIG	80.00	.2988	79.25	80.68
VELOCITY	60 FT/SEC	61.13	.552	59.27	62.59
GAS TEMP	2675 F	2670.	27.01	2597.	2751.
SRF TEMP	2450 F	2461.	23.33	2397.	2530.

................SPECIMEN HISTORY................

POSITION	SPECIMEN	INSTALLED	CYCLES	FUEL LEAN	FUEL RICH
#1	HPBR-4	28 APR 1993	6	1 HRS,3 MIN	16HRS,50MIN
#2	EMPTY		0	0 HRS,0 MIN	0 HRS,0 MIN

POS #1 (TOP): 1/2" BF GOODRICH SiC/SiC COMPOSITE (initial wt = 7.355 gm)
POS #2 (BOT): EMPTY

...................COMMENTS...................

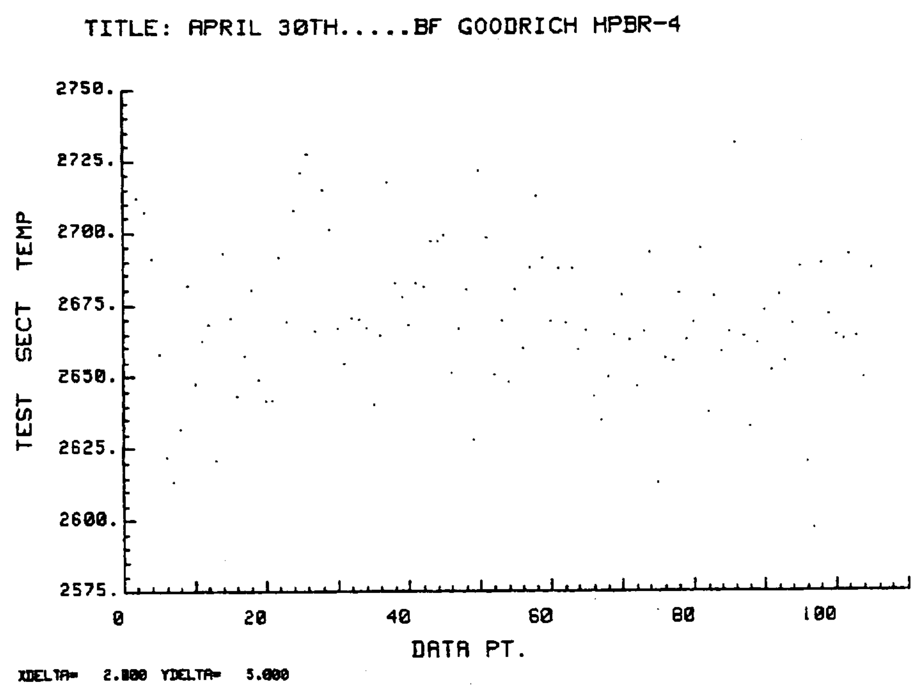

Figure 10.—Electronic test log and run summary printout including statistics and graphical data processing.

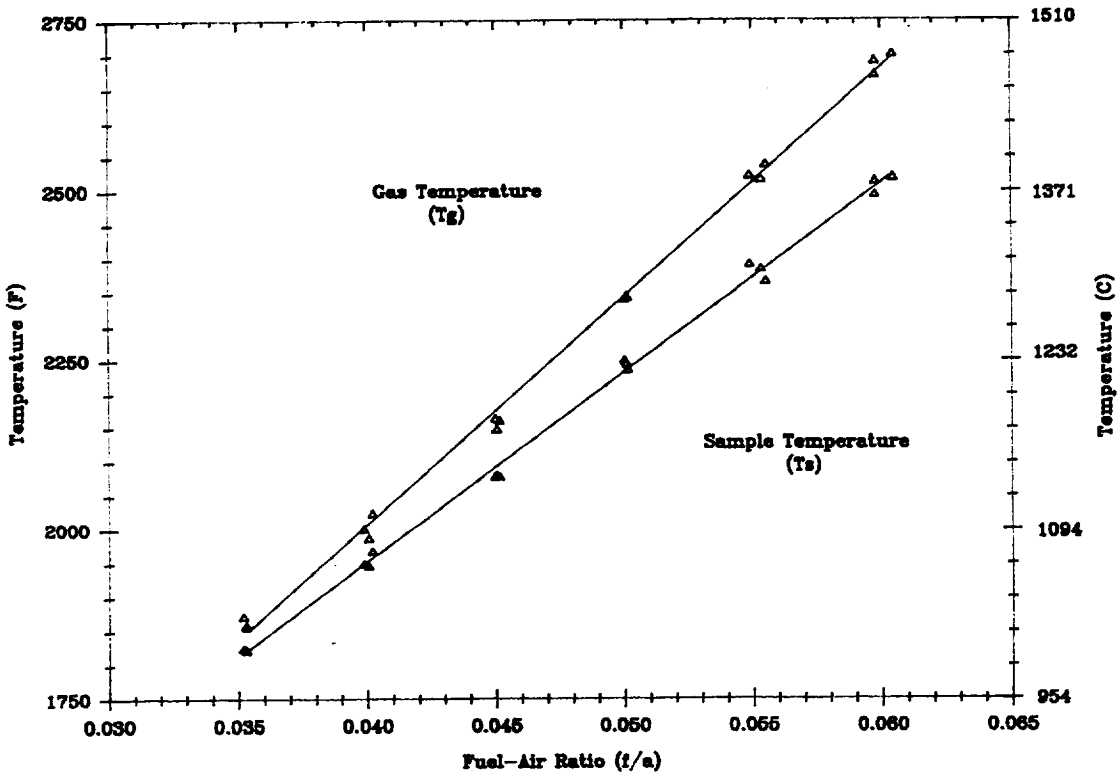

Figure 11.—Gas and test sample temperatures as a function of f/a ratio under lean-burn conditions.

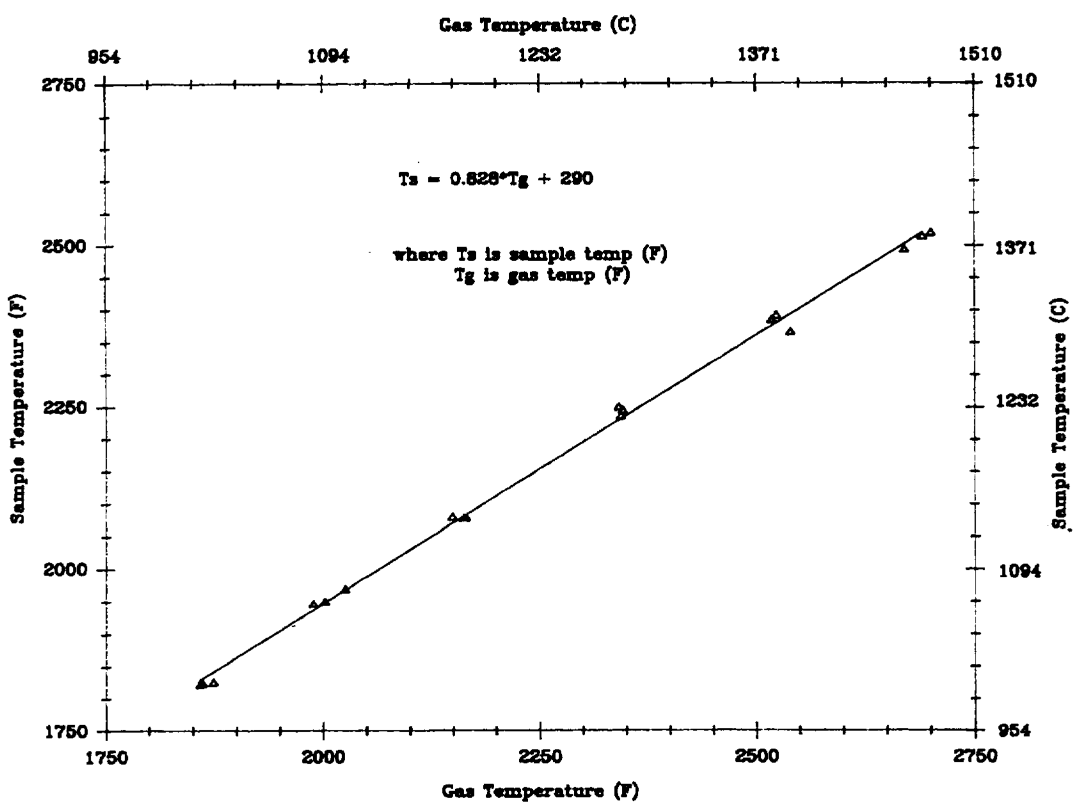

Figure 12.—Relationship between sample temperature and gas temperature.

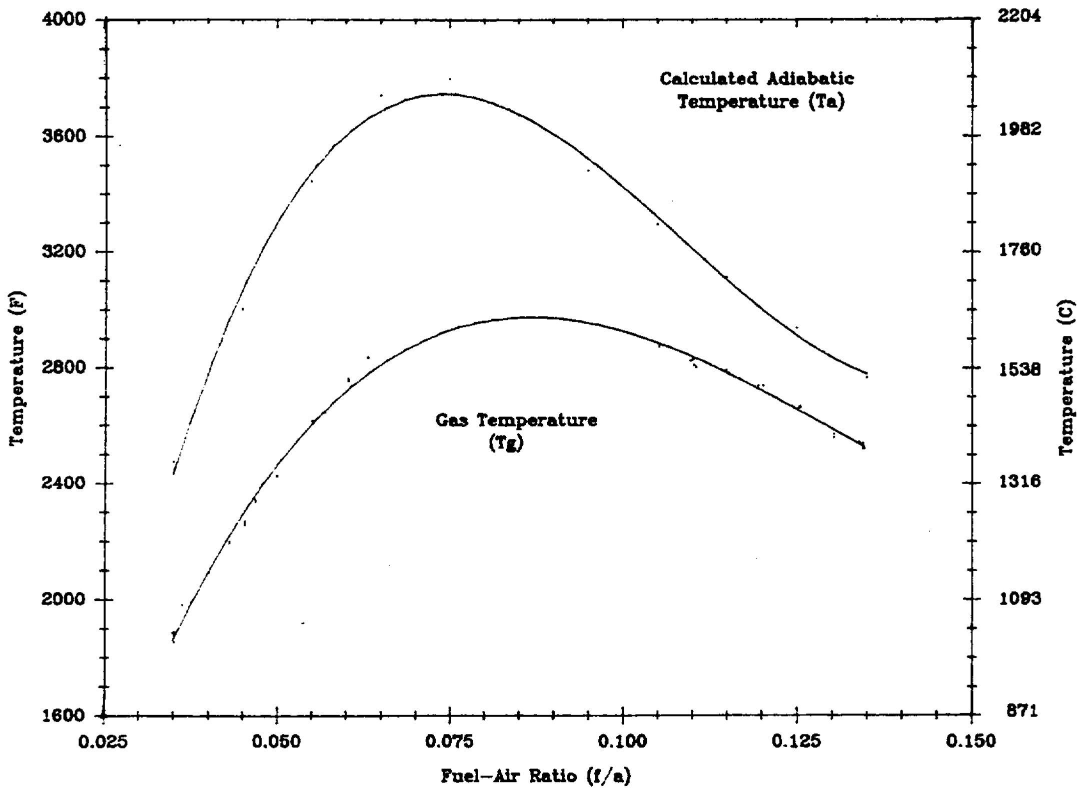

Figure 13.—Range of combustion gas temperatures available as compared to adiabatic conditions.

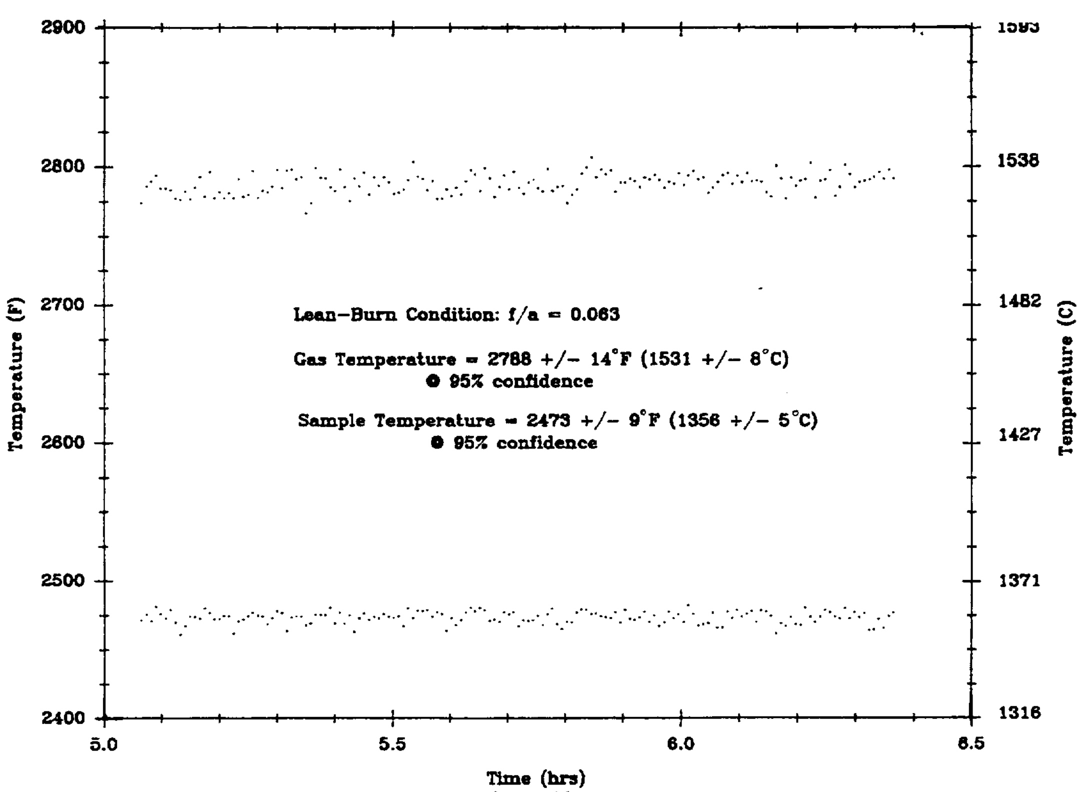

Figure 14.—Variation of gas temperature at fixed f/a ratio.

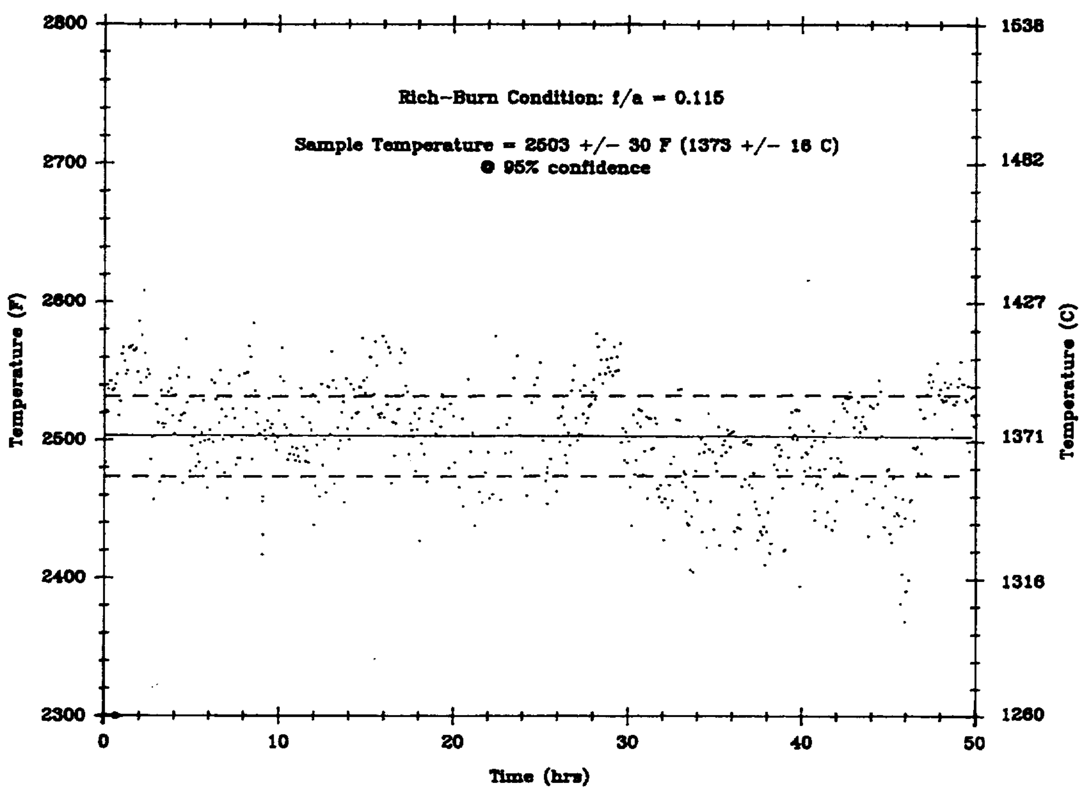

Figure 15.—Sample temperatures calculated using the lean-burn correlation during rich-burn testing.

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13. ABSTRACT ***(Maximum 200 words)***
The lean-, rich-burn materials test burner rig at NASA LeRC is used to evaluate the high temperature environmental durability of aerospace materials. The rig burns jet fuel and pressurized air, and sample materials can be subjected to both lean-burn and rich-burn environments. As part of NASA's Enabling Propulsion Materials (EPM) program, an existing rig was adapted to simulate the rich-burn quick-quench lean-burn (RQL) combustor concept which is being considered for the HSCT (high speed civil transport) aircraft. RQL materials requirements exceed that of current superalloys, thus ceramic matrix composites (CMC's) have emerged as the leading candidate materials. The performance of these materials in the quasi reducing environment of the rich-burn section of the RQL is of fundamental importance to materials development. This rig was developed to conduct such studies, and this report describes its operation and capabilities.

14. SUBJECT TERMS
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